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COLLISION AVOIDANCE SYSTEM ANALYSIS

VOLUME I

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IIT Research Institute

for

DEPARTMENT OF DEFENSE

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16. Abstract

Potential electromagnetic interference between the Collision Avoidance System (CAS) and both existing and future systems is addressed in this report. Frequency bands analyzed for the existing systems are the CAS RF band (1592.5 to 1622.5 MHz), and sub-harmonic and harmonically related frequency bands. Future systems considered are those that may operate in the 1535 to 1660 MHz frequency band. Equipments that operate in these frequency bands include television, tropospheric scatter and point-to-point communications, radar altimeters, and satellite relays. World-wide deployment of CAS is assumed for this analysis. Therefore, all frequency usage and allocation information available in the ECAC data files is considered.

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PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DOD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Director of Defense Research and Engineering and the Chairman, Joint Chiefs of Staff or their designees who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with task assignment 10, subitem d, of the Interagency Agreement DOT-FA70WAI-175 as part of AF Project 649E under Contract F-19628-71-C-0221 by the staff of the IIT Research Insitute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

Users of this report are invited to submit comments which would be useful in revising or adding to this material to the Director, ECAC, North Severn, Annapolis, Maryland 21402, Attention ACV.

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SECTION 1

INTRODUCTION

BACKGROUND

During 1955, the scheduled airlines and the Air Transport Association of America (ATA) established the goal of developing a Collision Avoidance System (CAS) for use by the airlines and other aircraft. The main purpose of CAS is to assist the pilot in maintaining a safe separation between all CAS-equipped aircraft. In addition, CAS must operate independently from, but be compatible with the Air Traffic Control System of the National Airspace System. Several organizations have worked on the design and development of CAS. These organizations include Bendix Avionics, McDonnell Douglas Corporation, and a team consisting of Sierra Research and Wilcox Electric Company.

CAS development has resulted in an automatic communication device which requires no pilot intervention until a collision threat is indicated. It operates on four discrete frequencies: 1600, 1605, 1610, and 1615 MHz. Each CAS-equipped aircraft automatically transmits sufficient information for any other CAS-equipped aircraft to determine relative position and closure rate. With this information, the receiving CAS determines if a potential for a collision exists. If there is a collision threat, the pilot is warned and a preventive maneuver is indicated. A detailed technical description of CAS is presented in APPENDIX A of this report.

A 1968 ECAC report, ESD-TR-68-105, considered the electromagnetic compatibility among CAS, the Improved Glide Slope System, Air Traffic Control Satellite Systems, and Radar Altimeters allocated frequencies within the 1540 to 1660 MHz radio frequency band. Since publication of that report, a number of adjustments have been made to the suballocations of this frequency band. Also the lower limit of the band has been changed from 1540 to 1535 MHz. Many additional satellite systems have also been proposed for use in this band.

In September 1970, the Federal Aviation Administration requested ECAC to update the previous report in light of the frequency reallocations within the band, as outlined in Reference 1. This new analysis was to place particular emphasis on interference to CAS.

OBJECTIVES

The objectives of this analysis were to:

1. Perform an analysis to determine interference to CAS from existing systems with special emphasis on radar altimeters.
2. Perform an analysis of the interaction of CAS with future systems with special emphasis on aeronautical-satellite systems.

APPROACH

The approach to satisfying the objectives consisted of five tasks:

1. Perform a search of ECAC files to identify and locate, on a world-wide basis, the existing equipments that operate in the CAS RF, subharmonic and harmonic frequency bands.
2. Participate in the CAS/radar altimeter interference tests, and reduce the test data for application to the analysis.
3. Develop a computer program for efficiently generating the potential interfering signals that would be received by CAS in any given multiple-equipment environment. Use this program, the Signal Environment Model, in the CAS/radar altimeter analysis.
4. Perform a search of pertinent ECAC data files and various publications for future systems that may operate in the 1535 to 1660 MHz frequency band. Discuss the results of this search with the FAA, to obtain their concurrence.
5. Prepare separate volumes presenting the unclassified (Volume I) and classified (Volume II) analyses.

SECTION 2

ANALYSIS OF EXISTING SYSTEMS

INTRODUCTION

Four categories of emitters that could potentially interfere with CAS receiver performance were examined: sub-harmonic, in-band, adjacent-band and harmonic. Sub-harmonic emitters are defined as those that have harmonics in the 1592.5 MHz to 1622.5 MHz range. In-band emitters are defined as those emitters that are operated within ± 1 MHz of the four CAS frequencies (1600 MHz, 1605 MHz, 1610 MHz and 1615 MHz). Adjacent-band emitters are those that are within the 1592.5 MHz to 1622.5 MHz range but outside the ± 1 MHz segment at each CAS frequency. Harmonic emitters are those emitters operated at frequencies that are multiples (2, 3, 4 and 5) of the 1592.5 MHz to 1622.5 MHz range. Harmonic emitters were examined because of the potential of cavity and stripline preselectors to provide little attenuation to frequencies harmonically related to the designed passband. The frequency ranges applicable to each category are listed in TABLE 2-1.

TABLE 2-1

CAS RECEIVER ANALYSIS FREQUENCY CATEGORIES

Category	Frequency Range (MHz)
3rd Sub-harmonic	530.8 – 540.8
2nd Sub-harmonic	796.2 – 811.2
In-band	1592.5 – 1622.5[1]
Adjacent-band	1592.5 – 1622.5[2]
2nd Harmonic	3185.0 – 3245.0
3rd Harmonic	4777.5 – 4867.5
4th Harmonic	6370.0 – 6490.0
5th Harmonic	7962.5 – 8112.5

[1] ± 1 MHz at 1600 MHz, 1605 MHz, 1610 MHz and 1615 MHz.

[2] Entire range except ± 1 MHz at each CAS frequency.

This section presents data on the emitters operating or authorized to operate at the time of the analysis. Although many of the emitters identified at specific locations may not be operational when CAS is deployed, these emitter types should be representative of the equipment environment at deployment. Specialized future systems being specifically authorized and designed to operate within the 1535 MHz to 1660 MHz band are discussed in Section 3.

Domestic military, governmental, commercial and private emitters as well as emitters used by U.S. forces and government agencies overseas are well documented. Emitter information of other countries is, at best, sketchy. Notifications of frequencies, not emitters, in use by other countries are registered by the International Telecommunications Union (ITU) only to the extent desired by the reporting nation. Frequencies used by governments and military organizations are rarely reported to the ITU.

All emitters and reported assignments contained in ECAC's computerized data base were reviewed. An emitter (this term incorporates assignments as well as particular equipment nomenclatures) qualified as an interfering source to the CAS receiver if it passed two basic tests. First, to be considered for further analysis, its operating frequency or tuning range had to be within one of the ranges listed in TABLE 2-1. Second, the emitter characteristics and operating constraints were examined. If, at a slant range separation distance of one mile, the interfering power at the CAS receiver exceeded one of the interference thresholds derived in APPENDIX B, the emitter was determined to be a potential source of interference. Free space propagation loss was used for all calculations.

All emitters passing the first test were grouped by function to indicate the types of equipment operating in each frequency range and to indicate whether a given type is expected to cause CAS receiver interference.

In the sub-sections which follow, two separation distances or two ranges of separation distance are often discussed. This situation occurs when the interfering source utilizes a directive antenna. (Only one distance or range of distances is discussed for omni-directional antennas.) The longer distance is applicable if the CAS equipped aircraft is exposed to mainbeam illumination. The shorter applies to sidelobe illumination.

Mainbeam gains for antennas were usually available. When they were not, values were assumed based on the functions of the emitters being considered.

All distance calculations for sidelobe illumination are based on a sidelobe gain of 0 dB.

SUB-HARMONIC ENVIRONMENT

Since certain classes of emitters have a greater potential to cause interference than other classes, this and the following sub-sections are organized by emitter function.

Harmonic effective radiated power (ERP) is considered to be 60 dB less than the fundamental ERP unless specific harmonic emission data is available.

The sub-harmonic emitters analyzed are tuned to, allocated to or have the capability to be tuned through frequencies within 530.8 MHz to 540.8 MHz or 796.2 MHz to 811.2 MHz.

Television Emitters

The frequencies of five domestic and four foreign TV channels are within the second and third sub-harmonics of the 1592.5 to 1622.5 MHz CAS band. TABLE 2-2 lists the channel numbers, frequency limits, general area of use and number of stations using a particular channel. The locations of the United States stations are shown in Figure 2-1. The foreign station locations are not plotted because of the quantity involved and the lack of resolution obtainable on a page size world map. The carrier frequencies, transmitter powers, call signs, coordinates, and city and state locations of the stations operating on the five domestic channels are contained in APPENDIX D. This appendix also lists city and country locations, coordinates and carrier frequencies for the stations operating on the four foreign channels.

An unmodified TV broadcasting antenna will have its mainlobe in the horizontal plane, i.e., at a zero degree elevation angle. In a large number of installations, due to antenna height, terrain and coverage desired, a TV station antenna will be designed with electrical and/or mechanical beam tilt. The tilt directs the mainlobe below the horizon into the population areas. The amount of tilt varies with each installation and can range from a fraction of a degree to several degrees. Mainlobe radiation above the horizon will potentially cause interference at a greater distance than will a mainlobe directed into population areas. To provide a conservative analysis and to avoid neglecting the TV antennas that do not incorporate tilt, a zero degree tilt antenna is considered.

Although a small number of TV stations employ antennas that are directional, omni-directional radiation is prevalent and will be considered here. The vertical radiation patterns of TV broadcasting antennas vary depending on the amount of tilt and null fill required for a given coverage. Eight vertical patterns for channel 24 were extracted from Federal Communications Commission license files. These patterns were overlaid and

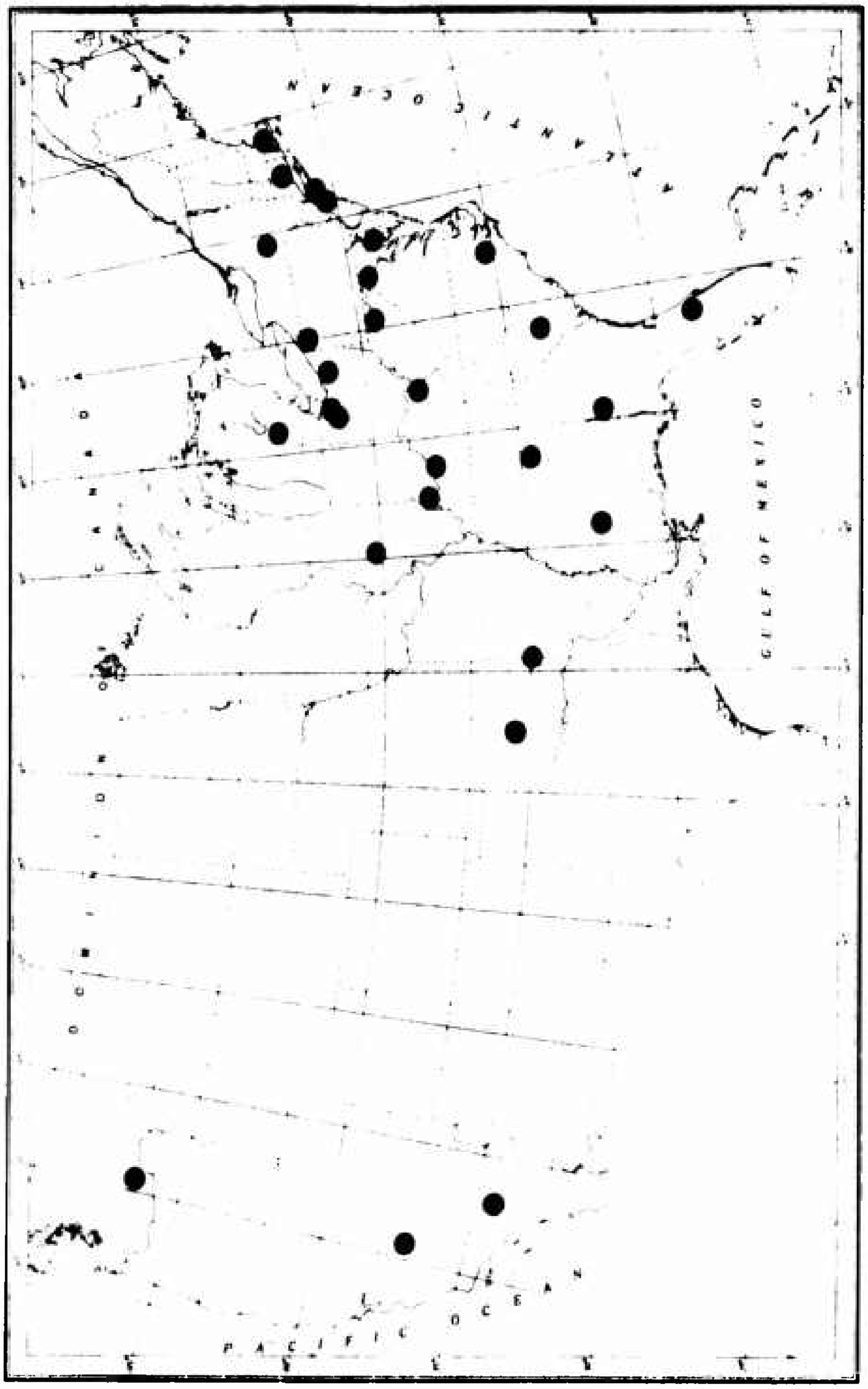

Figure 2-1. TV Stations in the CAS Sub-harmonic Frequency Bands

adjusted so that the mainlobe centers were coincident. The resulting synthesized vertical pattern, Figure 2-2, was used to determine the gain reduction at a particular elevation angle (Φ) relative to the gain at 0°. This pattern is 2.3 dB down at $\Phi = +1^\circ$ and about 6.5 dB down at $\Phi = +2^\circ$. The pattern falls off at a rate of 1.5 dB per degree for elevation angles above $+2^\circ$.

Free space propagation loss (L, in dB) as a function of frequency (f, in MHz) and distance (D, in nautical miles) is given by:

$$L = 20 \log f + 20 \log D + 37.8 \qquad (2\text{-}1)$$

solving for D at 1600 MHz:

$$D = \text{Antilog}\,[0.05L - 5.094] \qquad (2\text{-}2)$$

The propagation loss required to preclude TV harmonic interference to the CAS receiver may be expressed by:

$$L(\Phi) = ERP_H(0^\circ) - \Delta G(\Phi) + G_R - R_T \qquad (2\text{-}3)$$

where:

$L(\Phi)$ = The free space path loss at 1600 MHz as a function of Φ required to preclude exceeding R_T (dB)

$ERP_H(0^\circ)$ = The harmonic effective radiated power at 0° elevation angle (dBm)

$\Delta G(\Phi)$ = The gain reduction at the elevation angle Φ relative to the gain at 0° elevation angle (dB)

G_R = CAS receiver antenna gain (dB)

R_T = CAS receiver interference threshold (dBm)

Φ = Radio ray elevation angle (based on 4/3 earth radius) measured at the transmitting antenna (degrees)

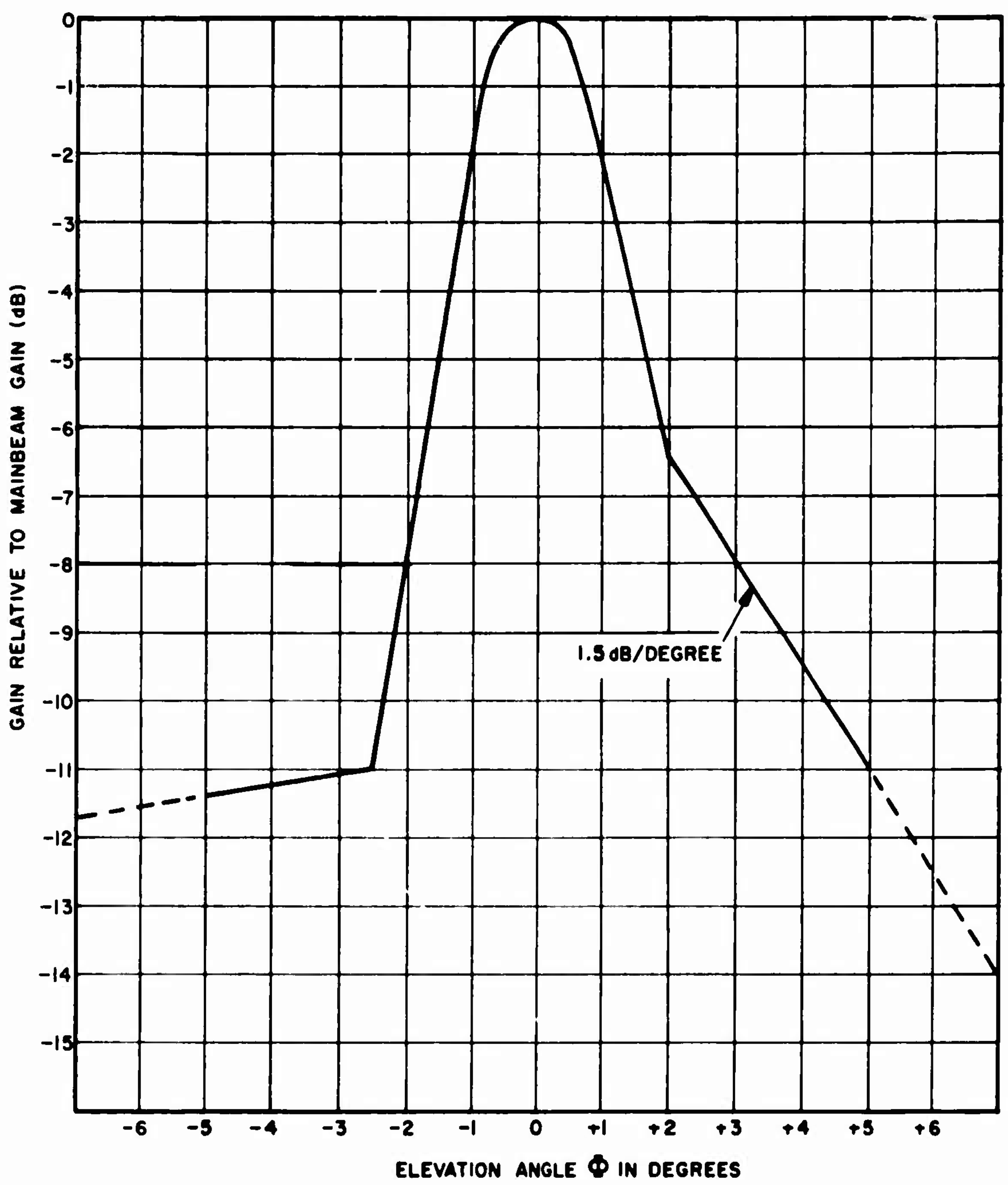

Figure 2-2. Synthesized TV Antenna Vertical Pattern - 0° Tilt

Three of the four variables in Equation (2-3) are known. WDCA channel 20, Washington, D.C., is reported to have the world's highest-powered (ERP) television transmitting facility. This station operates with 0.75° tilt with a mainlobe ERP of +96 dBm and a horizontal ERP of +95 dBm.

Each individual station has its own requirements for power and beam tilt. Rather than analyzing the characteristics of each station operating on the channels listed in TABLE 2-2, the WDCA mainlobe ERP, assuming 0° tilt, is used. Although conservative, this approach provides for station growth. Paragraph 73.687 (i), FCC Rules and Regulations, indicates all out-of-band emissions, interpreted by FCC to include harmonic emissions, must be at least 60 dB less than the video carrier power. The value of the first variable (ERP_H (0°)) in Equation (2-3) is, therefore, +36 dBm.

The CAS mean antenna gain is specified as +2 dB and cable loss is specified as 4 dB ± 2 dB (Reference 2, Attachment 1, para. 2.5.1). Assuming 2 dB of cable loss, the combined mean gain and cable loss provide an effective receiver antenna gain (G_R) of 0 dB.

The receiver interference threshold (R_T) of −95 dBm is derived in APPENDIX B. This level is 7 dB less than the operational sensitivity specified in Reference 2 (Attachment 1, para. 2.5.1).

Equation (2-3) is simplified by the substitution of the three terms just defined.

$$L(\Phi) = 131 - \Delta G(\Phi) \tag{2-4}$$

combining Equations (2-2) and (2-4):

$$D = \text{Antilog}\,[1.456 - 0.05\,\Delta G(\Phi)] \tag{2-5}$$

Equation 2-5 indicates that the required separation distance between TV emitters and CAS equipped aircraft is a function of the elevation angle of the aircraft relative to the transmitter antenna. Using values of $\Delta G(\Phi)$ from Figure 2-2, Equation (2-5), plotted in Figure D-1, provides an interference threshold in terms of separation distance and elevation angle.

The slant range separation distance between an aircraft and the transmitter antenna as a function of aircraft altitude above average terrain is shown in Figure 2-3. These separation distances were derived assuming mainbeam radiation from the top of a 1000 foot TV antenna. Except for mountain-top antennas, this is higher than most installations. The

TABLE 2-2

TV CHANNEL ALLOCATIONS IN THE CAS 2nd AND 3rd SUB-HARMONICS

Channel Number	Channel Limits (MHz)	General Location	Operating Stations
Domestic			
24	530-536	United States	11
25	536-542	United States	13
68	794-800	United States	3
69	800-806	United States	0
70	806-812	United States	1
Foreign			
28	526-534	Europe	57
29	534-542	Europe	50
62	798-806	Europe	4
63	806-814	Europe	7

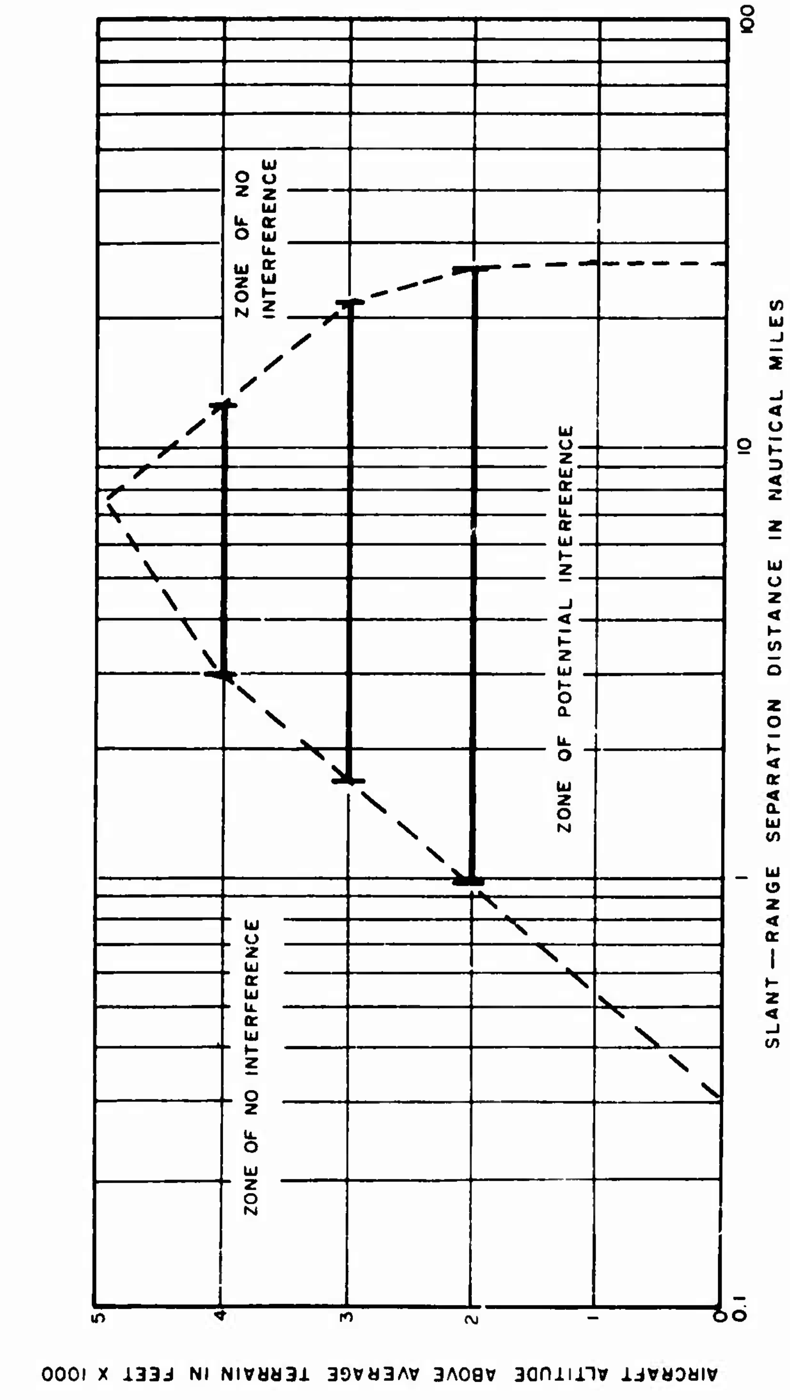

Figure 2-3. Required Distance Between CAS-Equipped Aircraft and TV Emitters to Prevent CAS Interference

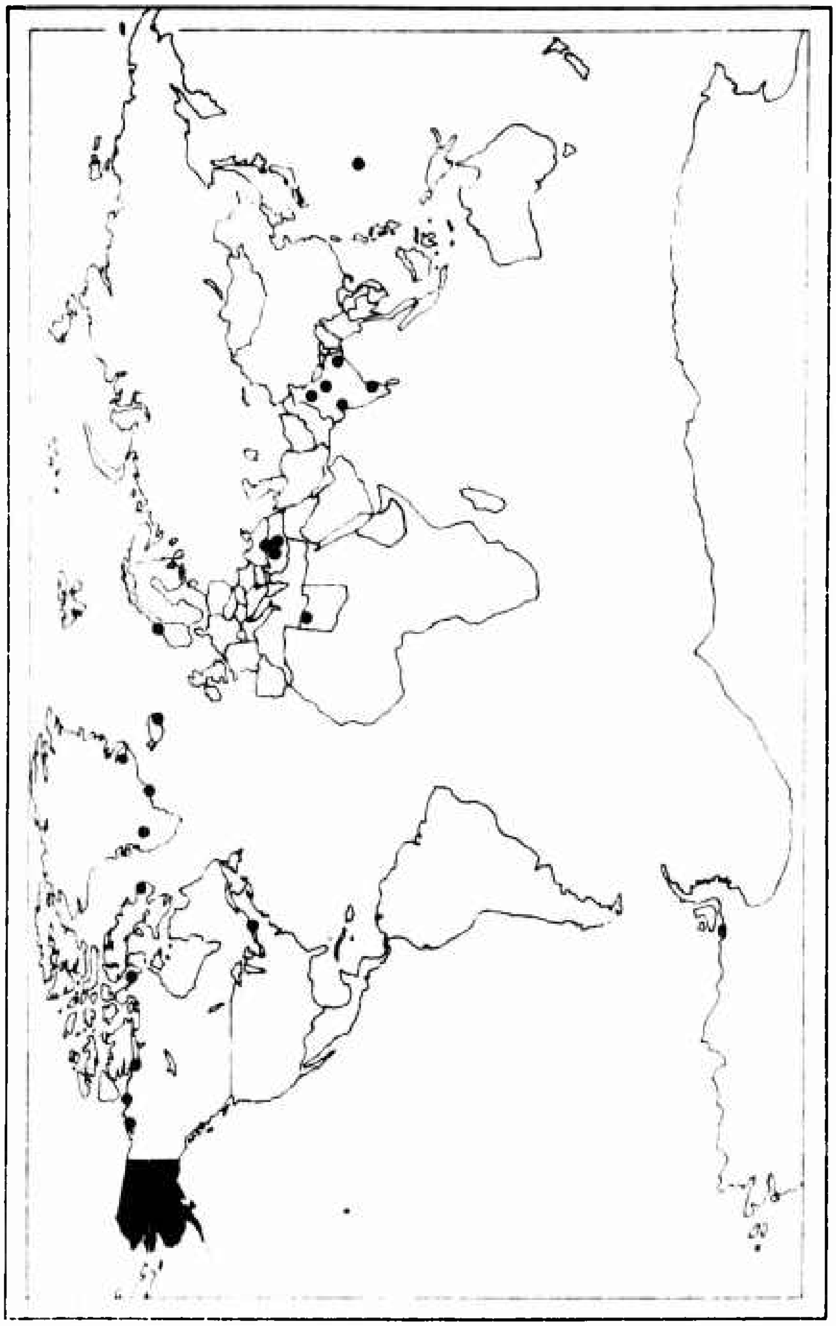

Figure 2-4. Tropospheric Scatter Terminals in CAS Sub-harmonic Frequency Bands

1. Transmitter harmonic power. Range: −10 dBm to + 17 dBm.
2. Emission bandwidth. Range: 4 MHz to 12 MHz. The emission bandwidth will usually be several times wider than the CAS receiver IF bandwidth and hence the receiver IF will not pass the entire TS signal.
3. Operating frequency: The TS harmonic may be outside the CAS receiver IF bandpass and be attenuated by the skirts of the IF filters.
4. Antenna gain. Range: +35 dBi to +49 dBi.

Tropospheric scatter terminals typically utilize transmitter powers equal to or greater than one kilowatt and antenna gains greater than 35 dBi. To minimize scattering loss, designers of TS links specify the lowest possible mainbeam elevation angles consistent with clearing terrain or obstacles in front of the antennas. These angles range from −1° to +3°.

The geometry of Figure 2-5 is configured to represent a typical antenna (for this frequency range) with a boresight elevation angle of 0.5° and a gain of 45 dBi. The antenna beamwidth is 1°.

An aircraft flying at 520 knots toward the TS site, in line with the mainbeam, at a 40,000-foot altitude would intercept the beam at an RLOS distance of 243 nmi. If the aircraft continued at this altitude and heading, it would exit the beam at a separation distance of 173 nmi. The time within the beam would be eight minutes. At the RLOS distance, a 1° beam has a width of about 4.3 nmi. If the aircraft were to orthogonally (at right angles) enter the beam at this point, it would traverse the beam in half a minute. Practically, if an aircraft does intercept the mainbeam, its flight time within the beam will be between half a minute and eight minutes.

If air routes or air terminals are located near TS emitter propagation paths, potential CAS receiver interference may occur. If these conditions exist and CAS interference is experienced, a route or flight pattern change may be warranted.

Miscellaneous Emitter Types

In addition to the TV and TS emitter classes, the analysis identified a number of other emitter classes operating within the CAS sub-harmonic categories. Emitters in these classes, listed below, are not expected to cause CAS receiver interference.

1. Measurement Instrumentation. Systems in this class consist of signal generators and directive antennas used for antenna pattern measurement and equipment shielding effectiveness evaluation.

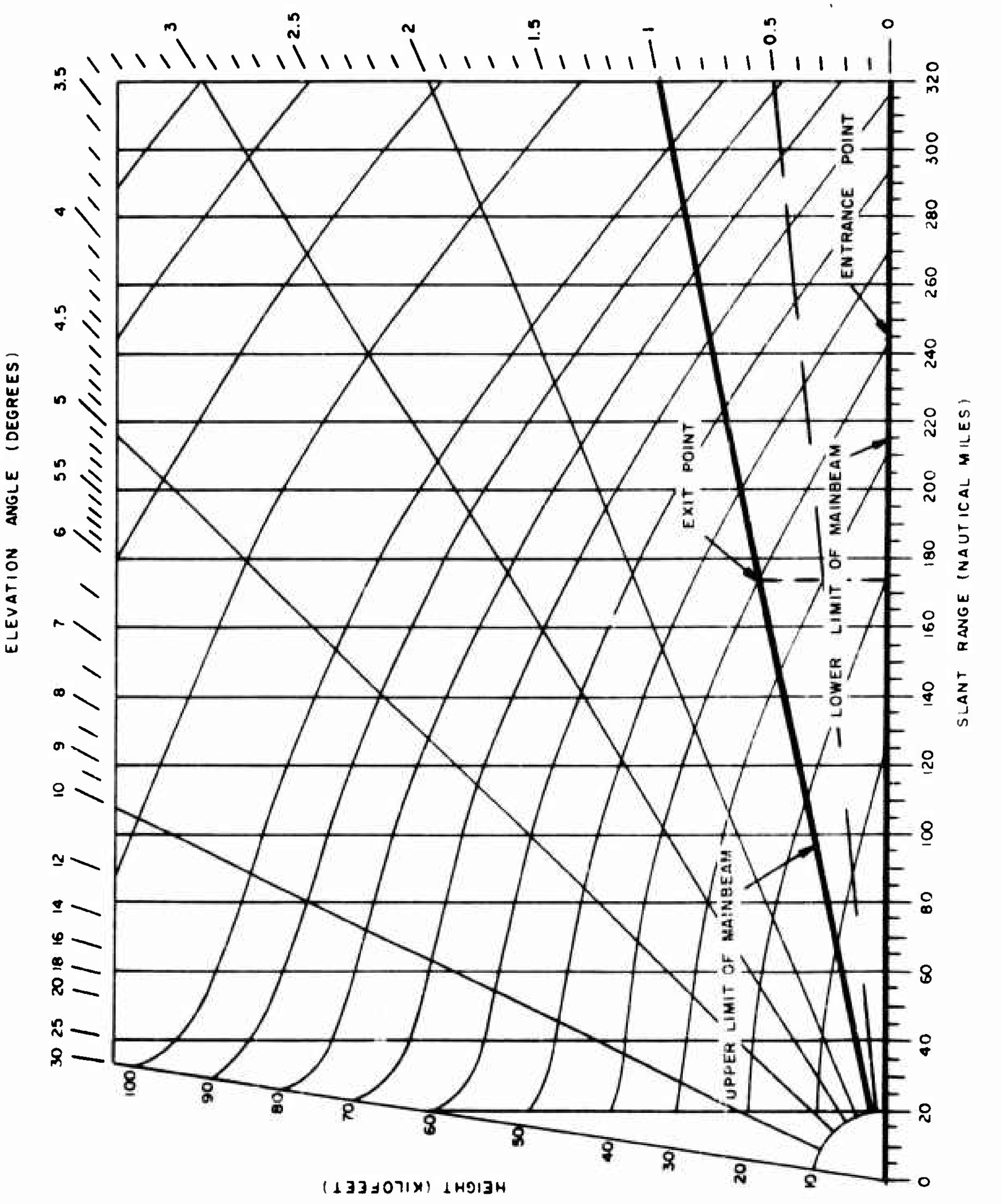

Figure 2-5. Typical Mainbeam Geometry for Tropospheric Scatter Antenna (800 MHz)

2. Data-Guidance Emitters. Systems in this class are used for telemetry and drone guidance. These systems normally utilize directive antennas that are auto-tracked or slaved to another antenna which is tracking the missile, drone, balloon, etc.

3. Military Training Emitters. This class includes Electromagnetic Countermeasures (ECM) and Radar Bomb Scoring (RBS) systems. These systems are used to train and/or evaluate the performance of personnel and equipment in a simulated, realistic field environment.

4. Short Line Communications Emitters. These point-to-point communications systems utilize widebeam directive antennas aligned with the receiving terminal antenna. All emitters identified in this class, fixed and mobile, were located in Germany and were operated by U.S. Forces.

IN-BAND AND ADJACENT-BAND EMITTERS

In-band and adjacent-band emitters are defined in the INTRODUCTION to Section 2. The rationale for combining these two categories, which encompass the same frequency range, follows:

1. The only specific equipment nomenclatures identified operate at frequencies within both categories.

2. The wideband communications systems identified have been allocated frequencies outside the CAS RF passband, but have emission bandwidths wide enough to spread into the passband. Hence, these systems also fit into both categories.

Narrow-Band Communications Emitters

Two narrow-band (1.2 MHz) emitter types (AN/GRC-50 and AN/GRC-50 V2) were identified to operate at six frequencies within the in-band or adjacent-band categories. These emitters, installed at five locations in central Germany, are used by the U.S. Forces for relay terminals. The five locations are represented by a single dot in Figure 2-6. The frequencies, coordinates, and locations of these emitters are listed in TABLE 2-2 of Volume II.

Each emitter is a potential interference source to the CAS receiver. The separation distance required to preclude interference ranges from 24 nmi to RLOS (243 nmi at a 40,000-foot altitude) for mainbeam illumination. For sidelobe and backlobe illumination the separation distance ranges from 3 to 61 nmi.

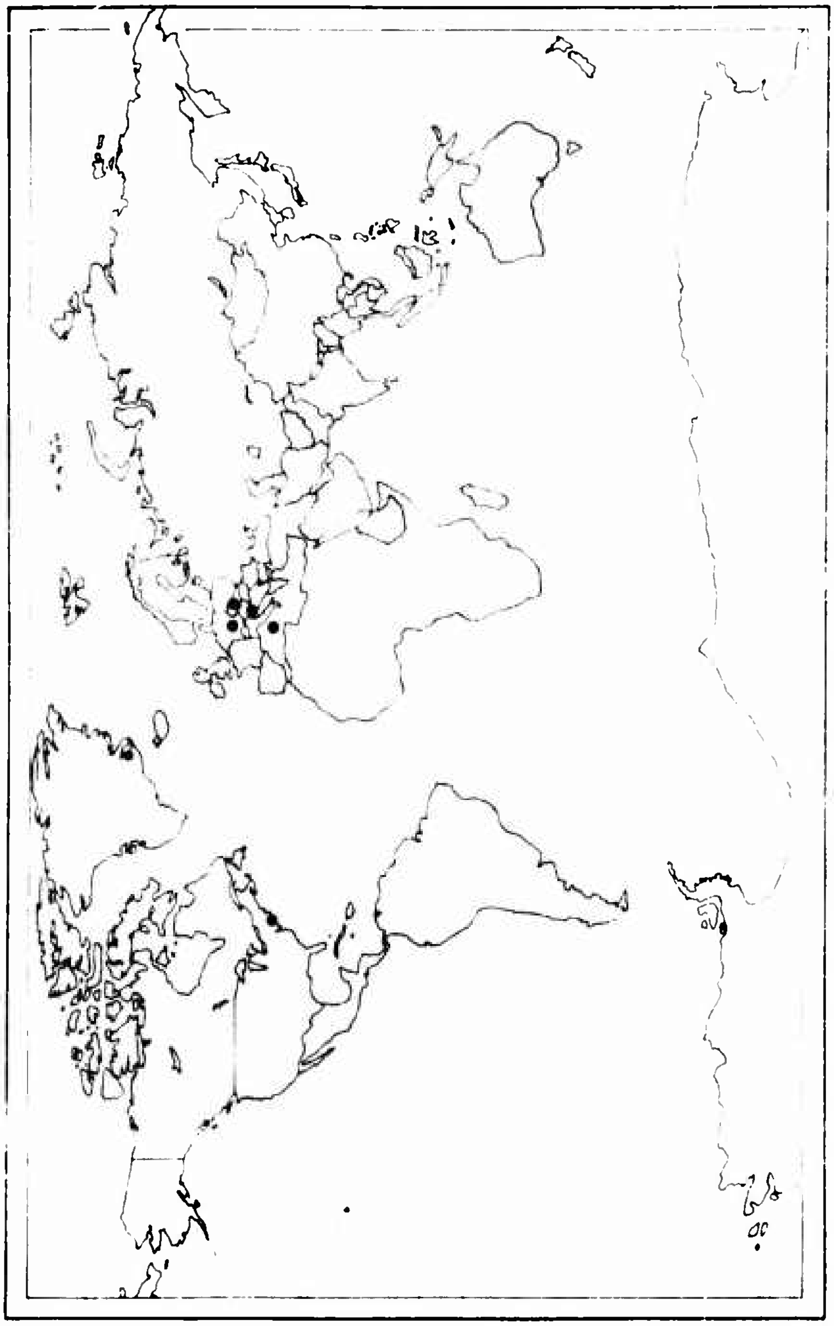

Figure 2-6. Emitters Either in or Adjacent to CAS Frequency Band

A range of distances is given for each type of illumination because these emitters are operated at a variety of frequencies with various transmitter power levels. The signal of an emitter tuned to a frequency within the CAS IF passband will receive little or no IF attenuation. Signals from emitters tuned within the RF passband but outside the IF passband will be attenuated by the receiver IF filtering.

Each emitter is reported to be operating with a 1.2 MHz emission bandwidth. This operation does not utilize the 2.25 MHz emission capability of the AN/GRC-50 series equipment.

The AN/GRC-50 series systems utilize an AT-903G horn antenna. This horn has horizontal and vertical beamwidths, respectively, of 20° and 16°. If the antenna is installed with a 0° elevation angle, the upper extreme of the mainbeam will occur at an eight degree elevation angle (Figure 2-7). Aircraft flying toward the terminal, along the antenna axis, at a 20,000-foot altitude will enter the mainbeam at the RLOS distance of 173 nmi. Continuing at this altitude and bearing, the aircraft would exit the beam at about 24 nmi. Hence, based on the mainbeam and sidelobe distance ranges, a CAS receiver could conceivably be exposed to continual interference when flying within sight of one of these relay terminals.

Footnote 352D, of the ITU Radio Regulations, states that the band 1540 MHz to 1660 MHz is allocated to the fixed service in the Federal Republic of Germany and other jurisdictions (Reference 3). The U.S. proposals for the World Administrative Radio Conference (WARC) for space telecommunications (Reference 1) do not indicate a change to this allocation. Either this allocation should be altered or the operating frequencies of these emitters should be changed to frequencies removed from the CAS receiver RF passband. If neither of these provisions are executed and present operation continues, interference to CAS equipped aircraft in flight over central Germany is assured.

Wideband Communications Emitters

The frequencies of four ITU fixed service registrations are within the combined in-band/adjacent-band category. The emitters using these frequencies are located in Yugoslavia, Czechoslovakia and Italy. A single frequency is registered to a specific location in both Yugoslavia and in Italy. Two frequencies are registered for use throughout Czechoslovakia. These registrations are represented in Figure 2-6 by a dot in each country. TABLE 2-3 lists the frequencies, coordinates and locations for the registrations.

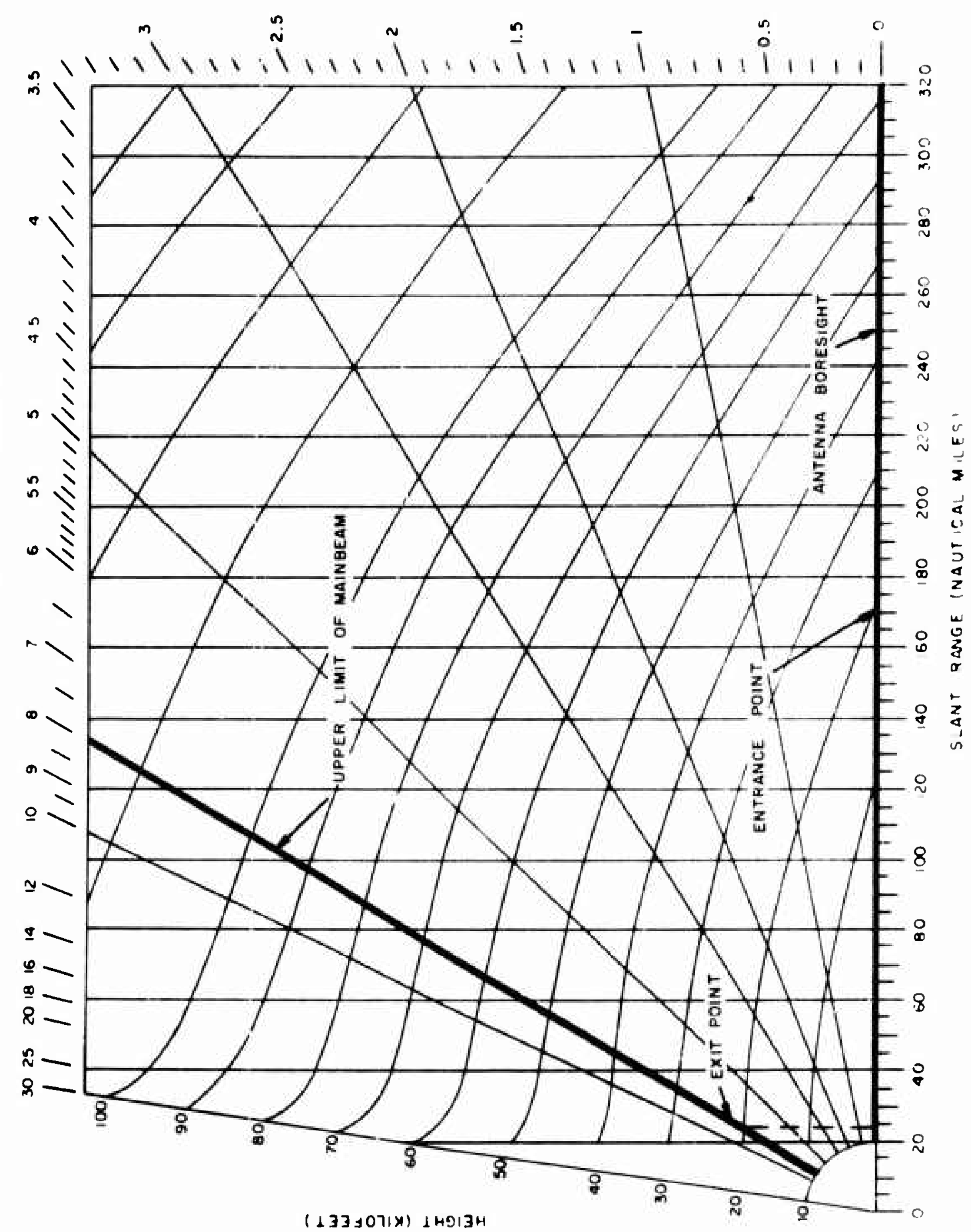

Figure 2-7. Typical Mainbeam Geometry for AT 903G Horn Antenna

TABLE 2-3

IN-BAND/ADJACENT-BAND FREQUENCY REGISTRATIONS

Frequency MHz	Latitude	Longitude	Location	
1595.0	46 14 00 N	015 32 00 E	Smarje	Yugoslavia
1595.0	49 09 00 N	008 38 00 E	Badde Urbara	Italy
1612.5	- - -	- - -	Country Wide	Czechoslovakia
1612.5	- - -	- - -	Country Wide	Czechoslovakia

The Yugoslavian emitter operates in a band assigned by international radio regulations to aeronautical radio navigation (1540 to 1660 MHz). Yugoslavian radio regulations presumably allow fixed service operation in this band on a non-interfering basis. This operation is similar to that of seven other Warsaw Pact countries (Reference 3, Footnote 352).

The 3.6 MHz emission bandwidth and the F3 modulation type indicate the emitter is used for multichannel voice communications. The ITU registration for this emitter lists non-directional antenna coverage. Multichannel information could be radiated a short distance by the +40 dBm emitter and an omnidirectional antenna. Assuming a +10 dBi omni antenna, CAS receiver interference could occur within a radius of 12 nmi.

Although omnidirectional radiation is feasible, greater range can be obtained by another method. The emitter could service a number of receivers (at specific azimuths) by radiating from small parabolic antennas (three foot diameter assumed) clustered around a single tower. For the cluster configuration CAS receiver interference is anticipated within 42 nmi for mainbeam illumination and within four nautical miles for sidelobe illumination.

The Czechoslovakian emitters are probably part of a point-to-point wideband communications net. High gain (+30 dBi) directive antennas are, therefore, assumed. The separation distance for mainbeam illumination is 243 nmi, which is the RLOS distance at a 40,000-foot altitude. The sidelobe separation distance is 8 nautical miles. These distances are based on a +33 dBm emitter with a 12 MHz emission bandwidth.

Aircraft flying toward the emitter, along the antenna axis, at 40,000 feet would enter the mainbeam at the RLOS distance. If the aircraft did not alter its course or altitude, it would exit the beam at 103 nmi (Figure 2-8). These distances are based on an antenna with a 0° elevation angle. The aircraft would then be in an interference-free zone until it approached within 8 nmi (sidelobe separation distance) of the emitter.

An aircraft flying at 520 knots in the mainbeam at 40,000 feet will remain in the mainbeam interference zone for a period ranging from three to six minutes. This period is dependent on the angle at which the aircraft intercepts the beam.

Since the ITU allocation indicates these emitters may be located throughout the country, it is anticipated that CAS equipped aircraft in flight over Czechoslovakia would periodically fly in and out of interference.

The Italian emitter at 1595 MHz utilizes a high gain directive antenna similar to that which was assumed for the Czechoslovakian communications net. Hence, Figure 2-8 is also applicable to the Italian emitter.

A CAS equipped aircraft at 40,000 feet will be exposed to interference within 243 nmi of this emitter. Sidelobe interference should not occur until the aircraft approaches within 12 nmi. The mainbeam entrance and exit points (Figure 2-8) are, respectively, 243 nmi and 103 nmi. A non-interference zone exists from the exit point to the 12 nmi sidelobe interference distance.

Footnote 351, ITU Radio Regulations (Reference 3) allocates the band 1535 MHz to 1600 MHz to the fixed service in Italy until 1 June 1970. Although this date has passed, consideration may exist to extend this allocation. The U.S. WARC proposals, Reference 1, advise the deletion of this footnote. Such action would preclude CAS receiver interference from fixed service Italian emitters.

Miscellaneous Emitter Types

In addition to the two emitter classes discussed, the analysis identified two other classes operating within this combined category.

1. Measurement Instrumentation. Systems in this class include signal generators and directive antennas used for antenna pattern measurement and equipment shielding effectiveness evaluation.
2. Electronic Countermeasures Systems. This class includes a variety of emitter types designed specifically to cause interference. One such emitter discussed in the classified volume.

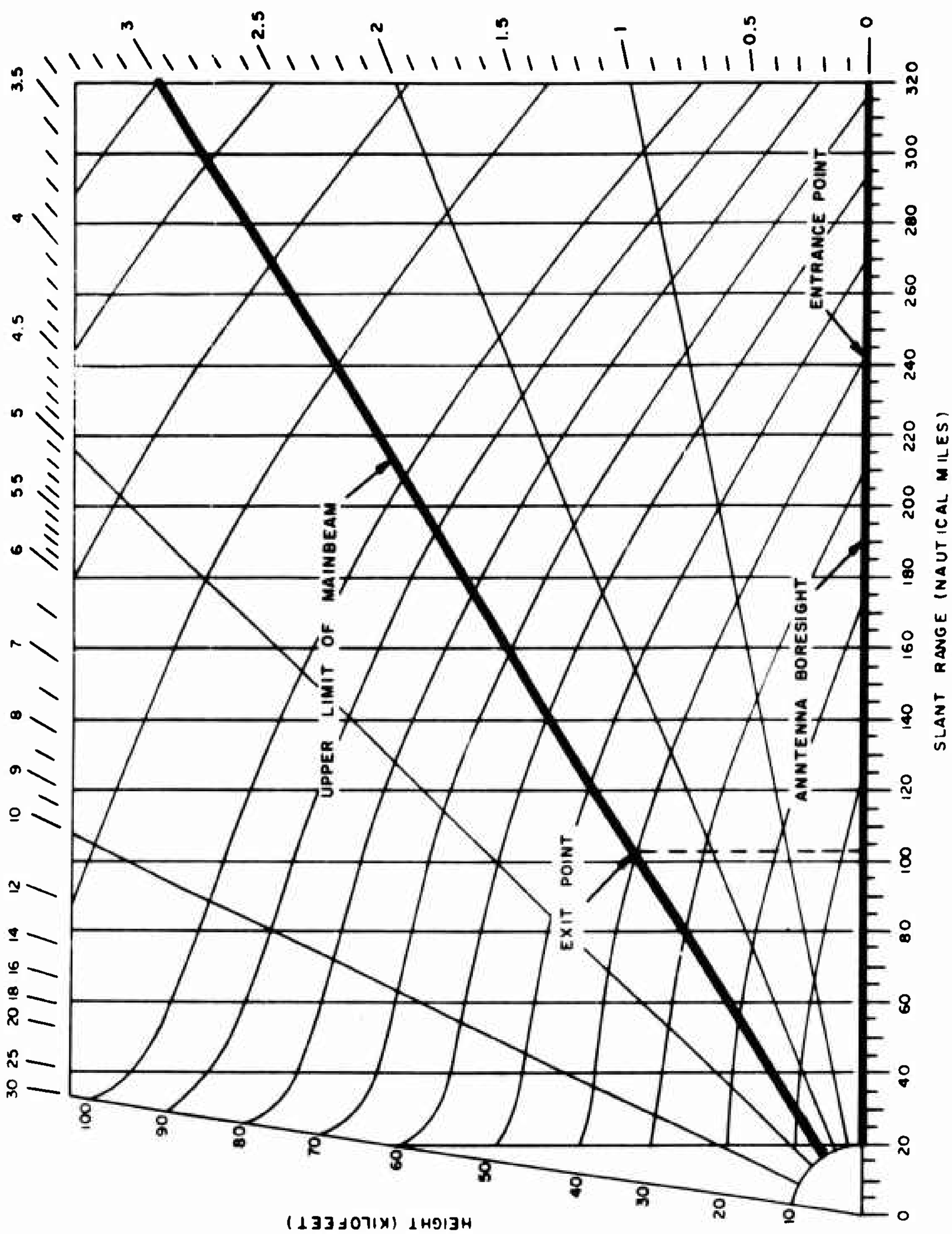

Figure 2-8. Typical Mainbeam Geometry for Wideband Communications Antennas

Emitters used for test and evaluation purposes are used on an aperiodic basis. Nevertheless, even occasional radiation in the CAS band could be detrimental to aircraft safety. One contractor has found a workable solution when his equipment must radiate in bands allocated to aircraft safety aids. The emitter aircraft is equipped with a telephone having its own private number. The area air traffic controller and frequency coordinator are notified of the type of test to be conducted, testing area and duration. Should either observe harmful interference to facilities under his jurisdiction, an immediate call is made to the aircraft requesting termination of the testing.

Contractors and military organizations engaged in domestic peacetime ECM activities function in a similar manner. If surface based, ship based or large scale airborne (seven or more aircraft involved) ECM operations are to be conducted, notification must be sent to a number of interested agencies in the United States and Canada. Small scale airborne (six or less aircraft involved) ECM operations apparently do not require this notification. Aircraft involved in ECM evaluation are required to continually monitor the 243 MHz and 121.5 MHz guard frequencies. Should interference be attributed to the ECM operation, the aircraft can be immediately requested to terminate the operation.

Air Force regulation AFR 55-44, (Reference 4), attachment 1, indicates that the bands from 1540 MHz to 1600 MHz and 1600 MHz to 1660 MHz are "authorized" for ECM operation. Since a portion of this band may be allocated to CAS, consideration should be given to changing these bands to "restricted" or "local" usage.

RADAR ALTIMETER INTERFERENCE

APPENDIX B outlines the CAS/radar altimeter interference tests and the interference criteria development for CAS. It is shown in this appendix that a peak power signal level of −73 dBm in the CAS IF will interfere with CAS reception of signals from aircraft at the TAU 2 boundary. This was based on two head-on, co-altitude aircraft flying at speeds of 1800 knots.

Minimum Separation Distances

Distances, beyond which no interference will occur, between an altimeter-equipped aircraft and a CAS-equipped aircraft, can be computed based on the peak power interference criterion. TABLE 2-4 shows these minimum-separation distances. They were calculated assuming mainbeam-to-mainbeam coupling, the altimeter operating at its nominal frequency, and CAS operating at 1615 MHz.

TABLE 2-4

TAU 2 PROTECTION CRITERIA

Altimeter		Minimum Distance Criteria (feet)
Type	Pulsewidth	
AN/APN-133A	120 ns	700
	500 ns	400
AN/APN-155A	- - -	600
AN/APN-159A	160 ns	63,000
	48 ns	71,000
IFD GAR	30 ns	700
Bonzer TRN-70	50 ns	300

As shown in TABLE 2-4 and mentioned in APPENDIX B, the CAS is apparently ultrasensitive to the AN/APN-159A emissions.This particular altimeter had been pulled from an aircraft production line and had passed inspection and, therefore, was considered as representative of all AN/APN-159As.

Altimeter Interference Within Aircraft Deployments

The Signal Environment Model (SEM) computer program was used to determine the impact of radar altimeters on a deployment of aircraft equipped with CAS. The airport option, as explained in Section 4, was used for the SEM analysis. Aircraft deployments as generated during the NAFEC[1] ATC/CAS simulation series were used as receiver deployments. The airport for these deployments was located at Washington National Airport. One transmitter deployment was used for all SEM computer runs. This deployment was taken from photographs of a radar plan position indicator at Suitland, Maryland. These photographs were taken during May, 1971, and show 189 aircraft within a 200 nautical mile radius of the radar.

[1] NAFEC: National Aviation Facility Experimental Center.

Six percent of the transmitter deployment were assumed to be equipped with military altimeters and ten percent with civilian altimeters. These percentages were considered by FAA as typical for an air terminal area. Percentages for each altimeter nomenclature were based on the two above percentages and the quantities shown in TABLE A-3. These final percentages are as follows:

	ALTIMETER NOMENCLATURES				
	AN/APN-133A	AN/APN-155A	AN/APN-159A	IFDGAR	Bonzer
Percentage	1	3.8	1.3	4	5.9

All aircraft within the receiver deployments were assumed to be equipped with CAS receivers. Several receiver deployments were used in order to define a trend in the expected number of received interference pulses and associated power levels. TABLES 2-5 and 2-6 are representative of the interference situation between the NAFEC receiver deployments and the Suitland transmitter deployment.

TABLE 2-5 shows the expected interference pulse counts per second and power levels that the average CAS-equipped aircraft would receive. The time slice number is the time in seconds during the NAFEC simulation that the aircraft deployment existed. A two minute interval was used between these time slices. TABLE 2-6 shows the highest number of expected interference pulses per second in each power range that was received by any CAS-equipped aircraft. TABLE 2-7 shows the cumulative number of CAS-equipped aircraft that are expected to receive the interference described in the previous tables. As an example, time slice number 33540 shows that 24 aircraft can expect to receive some interference at a power level of −70 dBm or greater. The number of received pulses per second are shown in TABLES 2-5 and 2-6. The AN/APN-159A was the only radar altimeter to cause interference at the power levels shown in these tables. The four remaining altimeters only cause interference below −90 dBm.

HARMONIC EMITTERS

Introduction

The CAS receiver is expected to utilize a stripline bandpass preselector to establish the RF bandwidth and thus attenuate frequencies outside this bandwidth. Stripline, cavity and similar preselectors inherently provide little or no attenuation at frequencies harmonically related to the designed (desired) passband. This minimal attenuation results in additional

TABLE 2-5

AVERAGE EXPECTED INTERFERENCE RECEIVED BY CAS RECEIVERS (PPS)

Time Slice Number	Received Peak Power Range (dBm)			
	−90 to −80	−80 to −70	−70 to −60	−60 to −50
33540	1468	305	63	5
33660	1468	312	62	5
33780	1493	326	62	10
33900	1497	324	53	6
34020	1466	338	69	9

TABLE 2-6

MAXIMUM EXPECTED INTERFERENCE RECEIVED BY CAS RECEIVERS (PPS)

Time Slice Number	Received Peak Power Range (dBm)			
	−90 to −80	−80 to −70	−70 to −60	−60 to −50
33540	2278	1186	437	62
33660	2278	1155	406	94
33780	2279	1061	343	125
33900	2372	1030	375	125
34020	2279	1155	375	125

TABLE 2-7

CUMULATIVE NUMBER OF DEGRADED CAS RECEIVERS

Time Slice Number	Receivers In Deployment	Received Peak Power Range (dBm)			
		−90 to −80	−80 to −70	−70 to −60	−60 to −50
33540	41	41	41	24	4
33660	42	42	42	22	4
33780	42	42	42	21	7
33900	41	41	41	22	3
34020	43	43	43	25	7

(undesired) passbands at multiples of the desired passband. Halfwave preselectors are characterized by undesired passbands at even multiples, i.e., second, fourth, etc. For quarterwave preselectors these undesired passbands occur at odd multiples, i.e., third, fifth, etc.

The frequency ranges of the second through fifth harmonic categories are defined in TABLE 2-1. Reference 5 indicates CAS designers are concerned with interference that would occur at the third and fifth harmonics of the preselector. By inference, a quarterwave device is being planned. Hence, only emitters operating in the third and fifth harmonic categories are examined. If a halfwave device were chosen, however, interference might occur at frequencies within the second and fourth harmonic categories.

For the purpose of this analysis, the CAS preselector is presumed to provide no attenuation in the harmonic passband and infinite attenuation outside this passband (an ideal filter). The harmonic passband is assumed to be N times as wide as the fundamental passband with a center frequency which is N times that of the fundamental passband (1607.5 MHz), where N is the number of the harmonic being considered.

Harmonic frequencies will be attenuated in the receiver mixer. The degree of mixer rejection is dependent on the mixer conversion efficiency at the harmonic frequency. The analysis is, therefore, reduced to a straight-forward spurious response problem.

The number of mixers, mixer type, intermediate frequency (IF) and local oscillator position (above or below the input frequency) will probably vary with each manufacturer. The spurious frequency analysis was based on a single conversion receiver utilizing a solid state diode mixer. Four intermediate frequencies are considered: 30 MHz, 45 MHz, 60 MHz and 160 MHz.

Equation 2-6 was used to calculate the theoretical spurious response frequencies for all combinations of the following parameters:

1. Thirty-two local oscillator frequencies (determined by the four CAS operating frequencies, the four intermediate frequencies and the two local oscillator positions).
2. Four intermediate frequencies.
3. Values of p ranging from one through seven.
4. Values of q ranging from one through ten.

$$f_{SP} = \frac{pf_{LO} \pm f_{IF}}{q} \tag{2-6}$$

where:

f_{SP} = Spurious frequency (MHz)

f_{LO} = Local oscillator frequency (MHz)

f_{IF} = Intermediate frequency (MHz)

p = Harmonic number of the local oscillator

q = Harmonic number of the spurious frequency

The calculated frequencies were automatically sorted by frequency and binned by harmonic category. Those frequencies outside the range of each category (that is, outside the assumed harmonic bandwidth) were rejected. Those within each category were printed with the parameters of Equation (2-6) that were used to determine each particular frequency. No spurious frequencies were identified in the fifth harmonic category. Those occuring in the third harmonic category are presented in TABLE 2-8 with their respective parameters. (Although not considered, spurious frequencies were identified in the second and fourth harmonic categories.)

ECAC has developed models for a variety of mixer types that can be used to determine the mixer rejection at spurious frequencies corresponding to particular combinations of p and q. Equations (2-7) and (2-8) were derived by Sell (Reference 6) for the solid-state diode mixer.

For: $p \geqslant 1, q = 1$

$$R = 29.7 \text{ Ln } (p) - 4.4 \tag{2-7}$$

For: $p \geqslant 1, q > 1$

$$R = \text{Ln } (p) + 13.5 \text{ Ln } (q) + 46.2 \tag{2-8}$$

where:

R = Mixer rejection relative to the $p = q = 1$ fundamental response

$\text{Ln } (p)$ = Natural logarithm of p

TABLE 2-8

THIRD HARMONIC SPURIOUS FREQUENCIES

IF Frequency MHz	Receiver Frequency MHz	LO Frequency MHz	LO Position Above/ Below	Spurious[1] Frequency MHz	Sign ±	q	p
30	1600	1570	B	NI	–	--	--
	1605	1575	B	NI	–	--	--
	1610	1580	B	NI	–	--	--
	1615	1585	B	4785	+	1	3
	1600	1630	A	4860	–	1	3
	1605	1635	A	NI	–	--	--
	1610	1640	A	NI	–	--	--
	1615	1645	A	NI	–	--	--
45	All	All	B/A	NI	–	--	--
60	All	All	B/A	NI	–	--	--
160	All	All	B/A	NI	–	--	--

[1] NI = None Identified in the Third Harmonic Category.

Ln (q) = Natural logarithm of q

p = Harmonic number of the local oscillator

q = Harmonic number of the spurious frequency

TABLE 2-9 presents the expected rejection values (in dB) calculated from these equations over the ranges of p and q for which the model is known to be valid.

The combinations of p and q that resulted in spurious frequencies in the third harmonic category (see TABLE 2-8) are used to enter the TABLE 2-9 matrix to obtain the rejection for that particular mix. The 28 dB rejection is used in the separation distance determination for those third harmonic emitters that either are tuned to a spurious frequency or have an emission bandwidth which encompasses a spurious frequency. It should be noted that this technique assumes that the local oscillator harmonics are well below the TABLE 2-9 rejection levels.

It is possible that values of p and q beyond the range of the solid-state mixer model may also result in theoretical spurious frequencies in the third or fifth harmonic categories. From TABLE 2-9 it is seen that the expected mixer rejection increases as p and q increase, and that the maximum rejection is about 79 dB. It is logical that combinations of greater p and q values will result in a rejection greater than 79 dB. Hence, a rejection of 80 dB is used in the separation distance determination for all fifth harmonic emitters and for those third harmonic emitters that do not occur on or spread into spurious frequencies.

The previous paragraphs have considered a harmonic passband which is N (harmonic number) times the bandwidth of the CAS preselector fundamental, designed, passband. For a third harmonic passband of 90 MHz (3 times 30 MHz) and a 30 MHz IF, it was shown that fourth order ($p = 3$, $q = 1$) spurious responses can exist within the third harmonic passband. It was also shown that selection of three other IFs, 45, 60 and 160 MHz, caused these responses to exist outside the 90 MHz passband. It is apparent, therefore, that the frequencies of the responses relative to the harmonic passband center frequency are a function of the IF.

To preclude potential interference from fourth order spurious responses in the third harmonic passband, the passband bandwidth should be *less* than two times the frequency separation between the spurious frequency and the third harmonic passband center frequency. Since the spurious frequencies are a function of the IF and the passband

TABLE 2-9

REJECTION IN dB FOR A SOLID-STATE DIODE MIXER

q \ p	1	2	3	4	5	6	7
1	0	16.1	28.2	36.4	43.3	48.7	53.3
2	55.5	56.3	56.7	57	57.2	57.4	57.6
3	61	61.7	62.2	62.5	62.7	62.9	63.1
4	64.9	65.6	66	66.3	66.6	66.8	66.9
5	67.9	68.6	69.1	69.4	69.6	69.8	69.9
6	70.4	71.1	71.5	71.8	72	72.2	72.4
7	72.4	73.2	73.6	73.9	74.1	74.3	74.5
8	74.2	75	75.4	75.7	75.9	76.1	----
9	75.8	76.6	77	77.3	77.5	77.7	----
10	77.2	78	78.4	78.7	78.9	----	----

bandwidth required to prevent interference is a function of the spurious frequencies, it follows that the passband bandwidth is also a function of the IF as is shown in Figure 2-9. This figure may be used to estimate the *ideal,* third harmonic passband bandwidth that should not be exceeded.

The following sub-sections presume a harmonic passband which is N times that of the CAS preselector fundamental passband. Only the frequencies of those emitters that may cause CAS receiver interference are identified; no effort is made to identify every allocation or assignment in the harmonic categories.

Third Harmonic Emitters

Emitters in this frequency category may generally be grouped into one of the following two functional classes of communications equipments.

1. Tropospheric scatter emitters. These emitters are characterized by relatively high transmitter power (usually greater than 0.5 kW) and antenna gain (30 dB to 40 dB). The antenna gains of TS emitters operating in the third harmonic band tend to be somewhat lower than the gains of emitters operating in the second sub-harmonic band.
2. Point-to-point, short haul, emitters. These are characterized by relatively low power (usually less than ten watts) and relatively high antenna gain (30 dB to 40 dB).

A number of equipments in each of these classes were allocated to a frequency band rather than to a specific frequency. To consider the possibility of an emitter with such an allocation being tuned to a spurious frequency, separation distance calculations were based on the 28 dB mixer rejection value.

The majority of the emitters identified as potential interference sources are either tuned to or spread into one of the spurious frequencies listed in TABLE 2-8. The distance calculations for these emitters were also based on 28 dB of rejection. It is again emphasized that careful intermediate frequency selection would significantly reduce or eliminate the interference effects of these emitters.

The locations of all potential third harmonic interference sources are plotted in Figure 2-10. A single dot may represent a number of emitters in the same general area or multiple emitters at a particular location.

Tropospheric Scatter Emitters. Seven specific frequencies and five frequency bands are utilized by or allocated to potential TS interference sources. Four frequencies are allocated

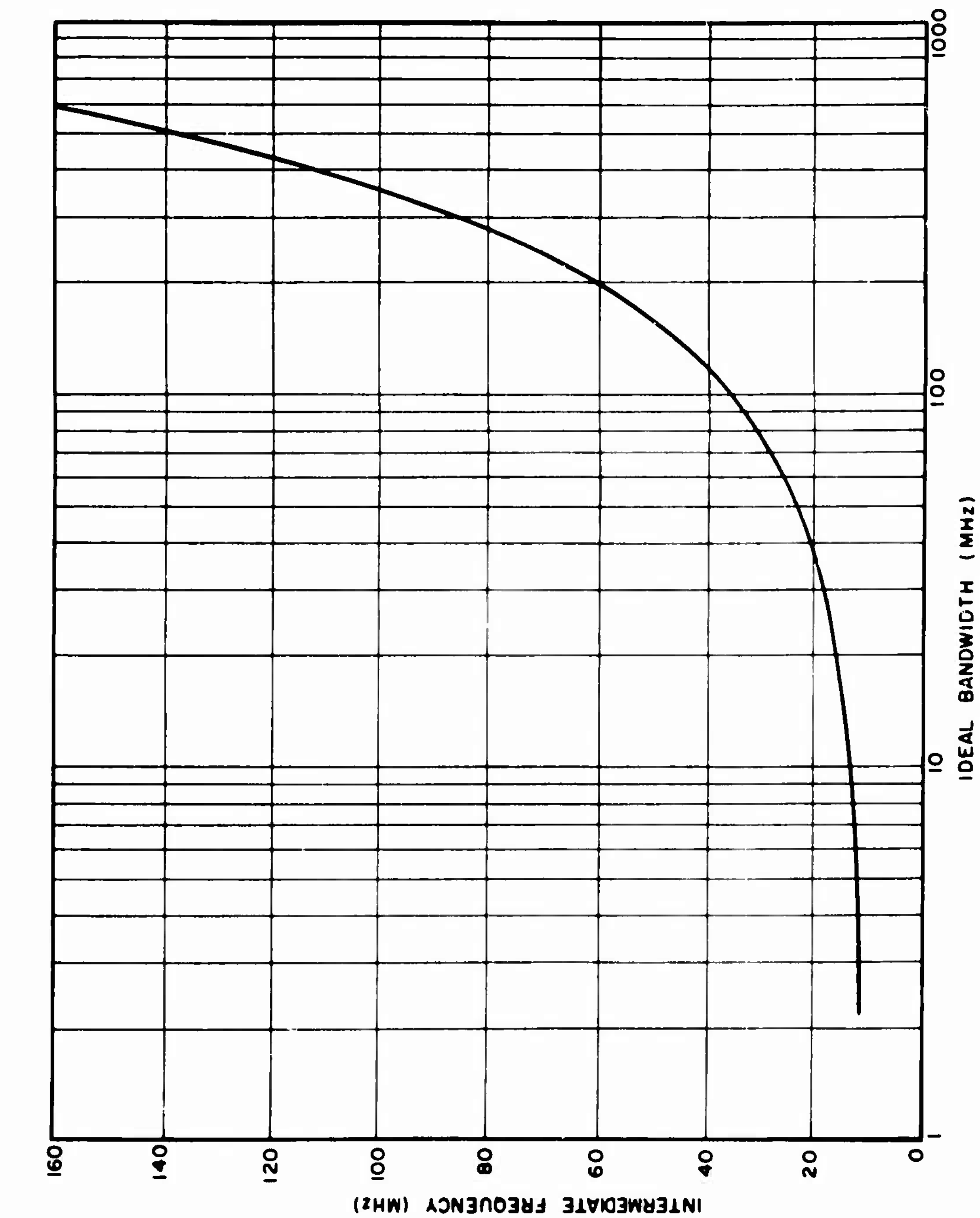

Figure 2-9. Ideal Third Harmonic Passband Bandwidth as a Function of the IF

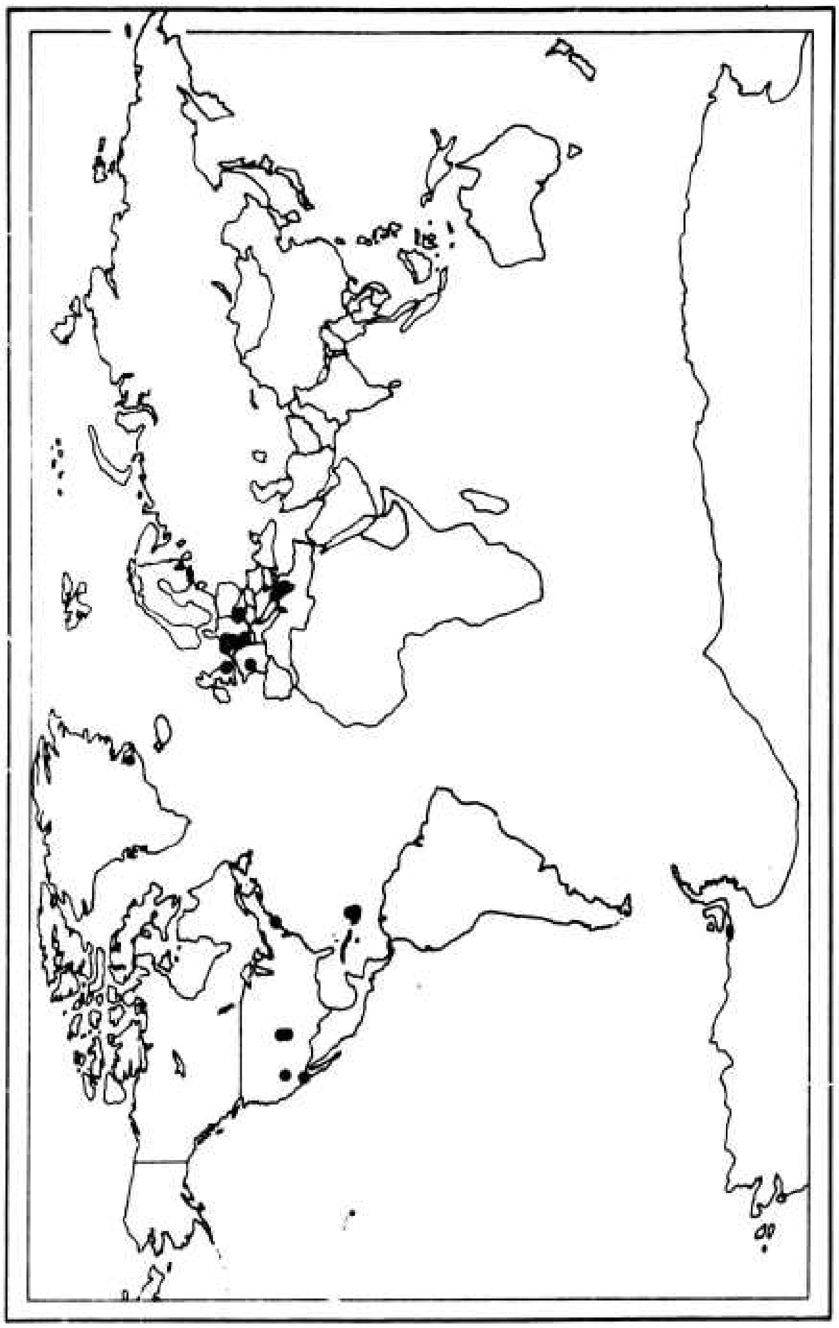

Figure 2-10. Emitters in the CAS Third Harmonic Frequency Band

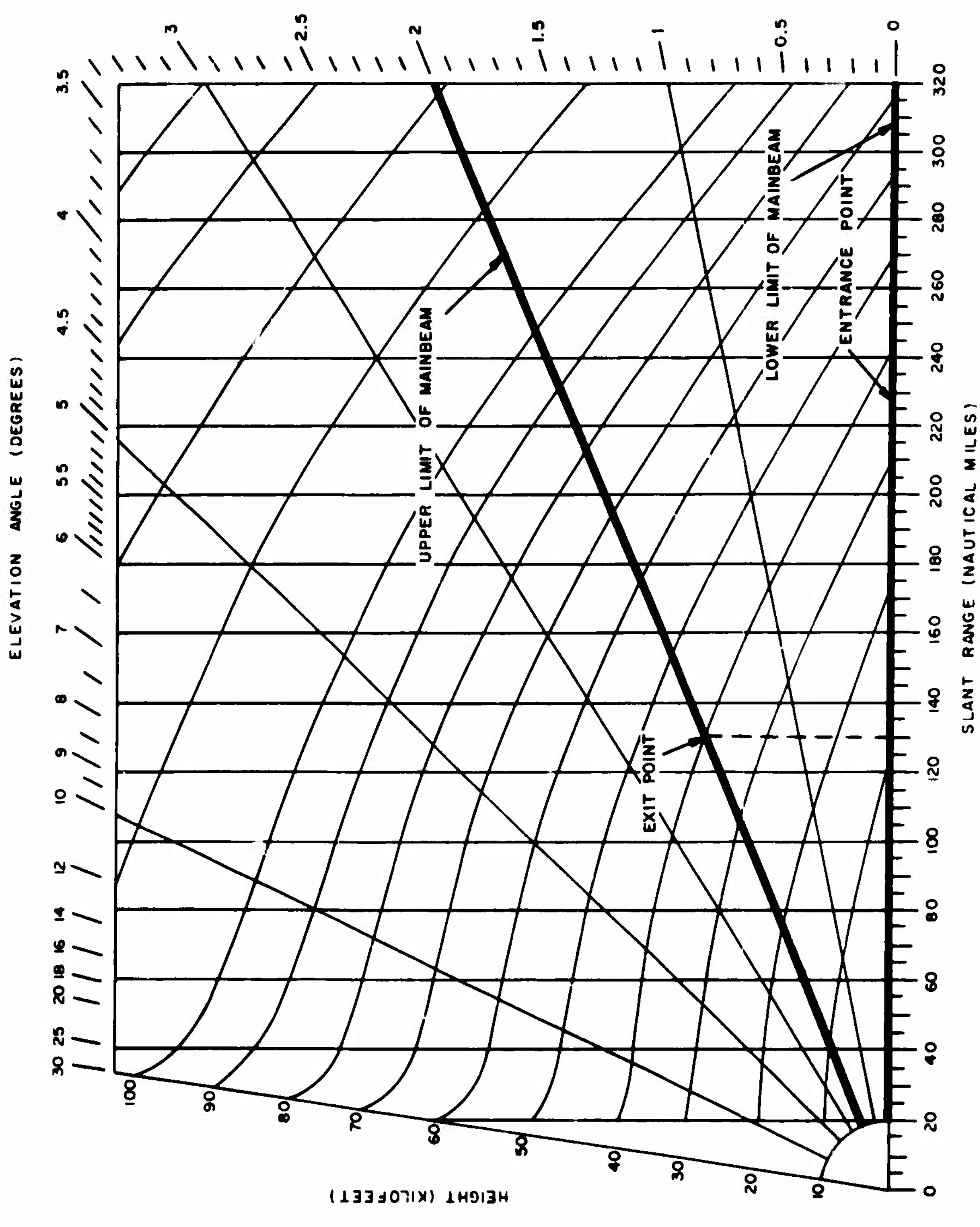

Figure 2-11. Typical Mainbeam Geometry for Tropospheric Scatter Antenna (4-5 GHz)

TABLE 2-10

THIRD HARMONIC EMITTER LOCATIONS

Frequency (MHz)	Latitude	Longitude	Location	
		Tropospheric Scatter Emitters		
4400.0 - 4990.0	18 07 00 N	065 30 00 W	Vieques	Puerto Rico
4400.0 4990.0	18 28 00 N	066 07 00 W	Ft. Brooke	Puerto Rico
4783.25	51 00 00 N	009 45 00 E	Countrywide	Germany
4786.75	51 00 00 N	009 45 00 E	Countrywide	Germany
4850.0 4860.0	38 23 00 N	103 09 00 W	Haswell	Colorado
4851.0 - 4859.0	40 08 00 N	103 15 00 W	Akron	Colorado
4858.75	51 00 00 N	009 45 00 E	Countrywide	Germany
4860.0	18 16 00 N	066 38 00 W	Roosevelt Rd.	Puerto Rico
4860.0	44 12 00 N	017 59 00 E	Zenica	Yugoslavia
4862.25	51 00 00 N	009 45 00 E	Countrywide	Germany
4862.5	18 16 00 N	066 38 00 W	Roosevelt Rds.	Puerto Rico
		Point-To-Point (Short Haul) Emitters		
4400.0 - 4990.0	40 10 11 N	074 30 00 W	Statewide	New Jersey
4780.0	41 06 00 N	021 23 00 E	Bitola	Yugoslavia
4783.25	52 15 00 N	005 30 00 E	Countrywide	Netherlands
4785.0	47 00 00 N	002 00 00 E	Countrywide	France
4787.5	39 00 00 N	116 30 00 W	- - - -	Nevada
4789.59998	47 00 00 N	002 00 00 E	Countrywide	France
4790.0	49 30 00 N	017 00 00 E	Countrywide	Czechoslovakia
4790.0	41 04 00 N	022 29 00 E	Djevdjelija	Yugoslavia
4858.59998	47 00 00 N	002 00 00 E	Countrywide	France
4862.5	39 00 00 N	116 30 00 W	- - - -	Nevada
4863.20001	47 00 00 N	002 00 00 E	Countrywide	France
4865.0	51 42 34 N	000 32 43 W	Bovingdon	UK Great Britain
		Miscellaneous Emitter Types		
4400.0 - 4990.0	18 07 00 N	065 30 00 W	Vieques	Puerto Rico
4400.0 - 4990.0	18 28 00 N	066 07 00 W	Ft. Brooke	Puerto Rico

for use throughout Germany. The remaining frequencies are allocated or used at specific locations. TABLE 2-10 provides the frequency, coordinates and location of most emitters. Those not listed in this table are presented in TABLE 2-3 of Volume II.

Because of the relatively low mixer rejection (28 dB) and the high effective radiated power, mainbeam and sidelobe TS emitter illumination can cause CAS receiver interference. The required separation distance to preclude this interference ranged from about three nmi to beyond RLOS (243 nmi at a 40,000-foot altitude) for mainbeam illumination. Only the distances for the Colorado and Yugoslavian emitters (about three and seven miles respectively) were less than RLOS. For sidelobe illumination the separation distance ranged from three to five nautical miles.

The geometry of Figure 2-11 is configured to represent a typical TS antenna (for this frequency range) with a boresight elevation angle of 1° and a gain of about 39 dB. The antenna beamwidth is 2°.

An aircraft flying at 520 knots toward the TS site along the mainbeam at 40,000 feet would intercept the beam at an RLOS distance of 243 nmi. If the aircraft continued along this flight path, it would exit the beam at a separation distance of 130 nmi. The flight time within the beam would be about thirteen minutes. At a distance of 243 nmi a 2° beam has a width of about 9 nmi. At this point an aircraft could orthogonally traverse the beam in half a minute. Practically, an aircraft flying into the mainbeam will be illuminated for a period of time between these two values. After leaving the beam, an aircraft heading toward the TS site would be in an interference-free zone until it approached within a few nautical miles of the site. Interference is not anticipated if the CAS equipped aircraft avoids mainbeam illumination and flies outside a five nautical mile radius from any TS site.

Point-To-Point (Short Haul) Emitters. Twelve frequencies and two allocated bands used by point-to-point emitters were identified (see TABLE 2-10). Although specific locations could be associated with a few of the frequencies, the majority of these point-to-point frequencies are assigned for statewide or countrywide use. Hence, a specific frequency may be used either at a large number of locations or from a mobile platform in the given state or country. The coordinates given in TABLE 2-10 for these frequencies are for the approximate center of the state or country listed. The locations are plotted with the other third harmonic locations in Figure 2-10.

Point-to-point emitters will potentially cause interference only if CAS equipped aircraft are illuminated by the emitter mainbeam. The separation distance to preclude this interference ranged from 3.5 to 15 nautical miles. The relatively short distances are attributable to the low transmitter power of these emitters.

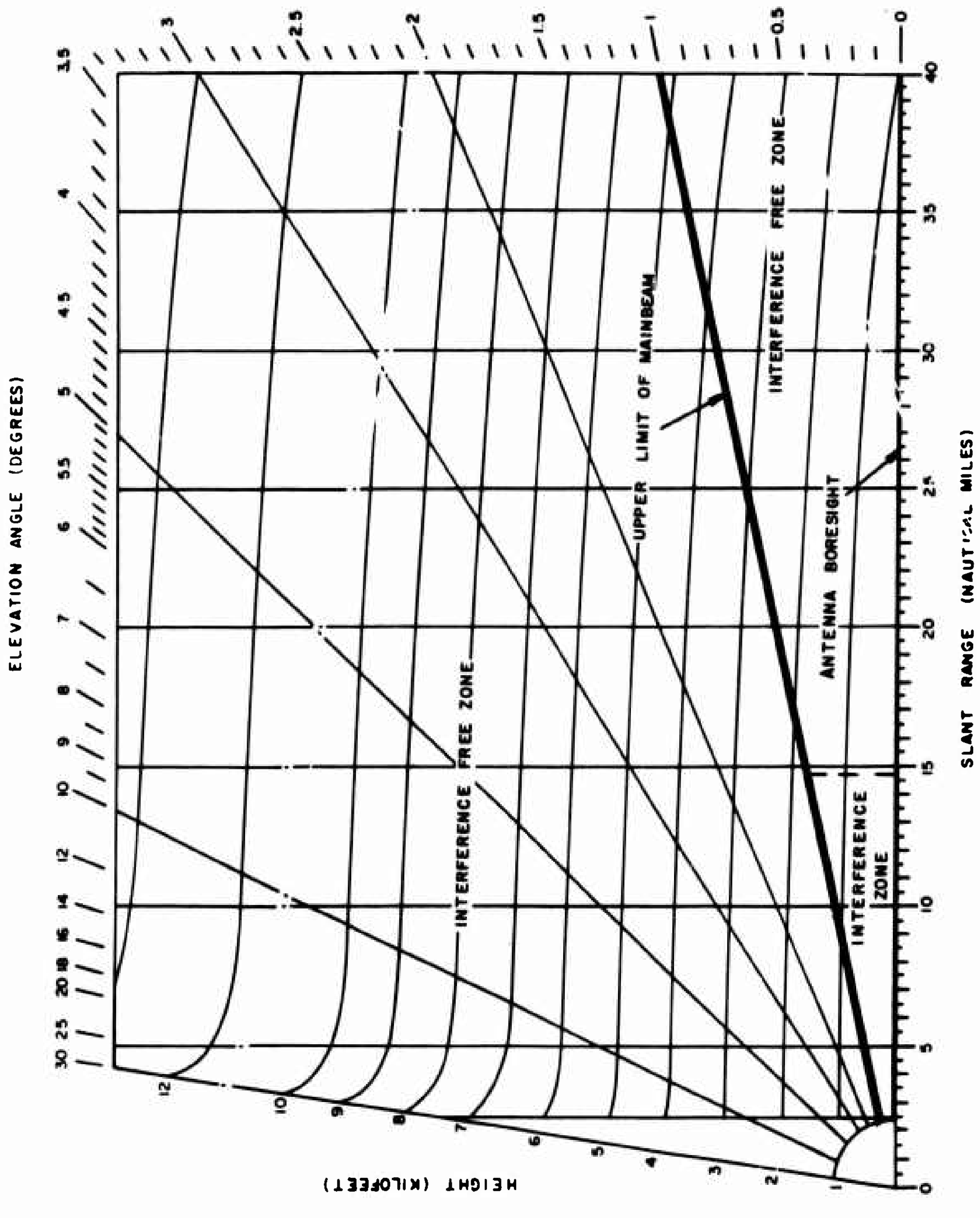

Figure 2-12. Mainbeam Geometry for Typical Short Haul Point-to-Point Communications Antenna

Figure 2-12 presents the mainbeam geometry of an antenna typically used for point-to-point communications in this frequency range. The beamwidth and elevation angle are respectively 2° and 0.5°. The maximum separation distance calculated 14.7 nmi, and the upper limit of the mainbeam define interference and interference-free zones. If CAS equipped aircraft fly above 1800 feet, the CAS receiver will not be subjected to interference. Therefore, interference is not anticipated unless approach or departure flight paths are in the vicinity of these emitters.

Miscellaneous Emitter Types. Two radars at separate locations in Puerto Rico are allocated to a band of frequencies that spreads through the third harmonic category. (See Figure 2-10 and TABLE 2-10.) It is expected that these radars will only cause CAS receiver interference if the CAS equipped aircraft were illuminated by the radar mainbeam. This interference would only occur if the aircraft were closer than 21 nmi from either of the radar sites. Since the radars may be utilized for a variety of functions, e.g., search and acquisition of aircraft, it is conceivable that the CAS receiver could be subjected to periodic or even continual interference if it were within 21 nmi of these radars.

The two additional equipment classes, measurement instrumentation and ECM systems, which are mentioned in previous subsections were also identified in the third harmonic category. With the exception of the ECM emitter discussed in Volume II (Section 2), equipment in these classes are not expected to interfere with CAS receiver operation.

Fifth Harmonic Emitters

The frequencies of 68 earth station emitters at 50 locations are within the fifth harmonic category. Most of these emitters serve as ground terminals for a global military satellite communications network. The terminal sites are plotted in Figure 2-13. Because of the map resolution and the occurrence of multiple emitters at one location, a single dot may represent more than one interfering source. The frequency, coordinates and locations of each emitter are presented in APPENDIX A of Volume II.

These emitters will potentially cause CAS receiver interference only if the CAS equipped aircraft is illuminated by the mainbeam of the earth station antenna. The required separation distance to preclude this interference ranged from 2 to 39 nmi depending on the system parameters at the station, i.e., transmitter power, emission bandwidth, operating frequency and antenna gain.

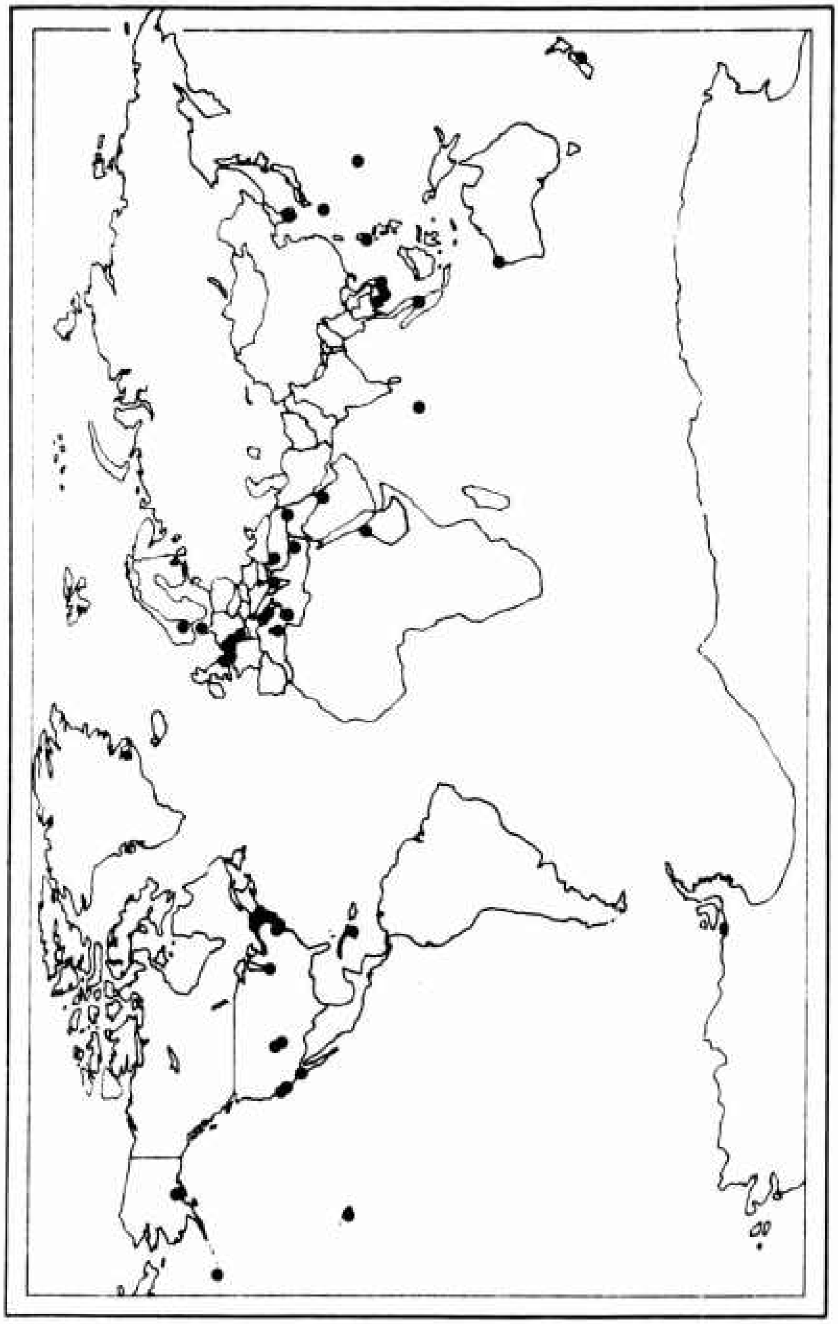

Figure 2-13. Emitters in the CAS Fifth Harmonic Frequency Band

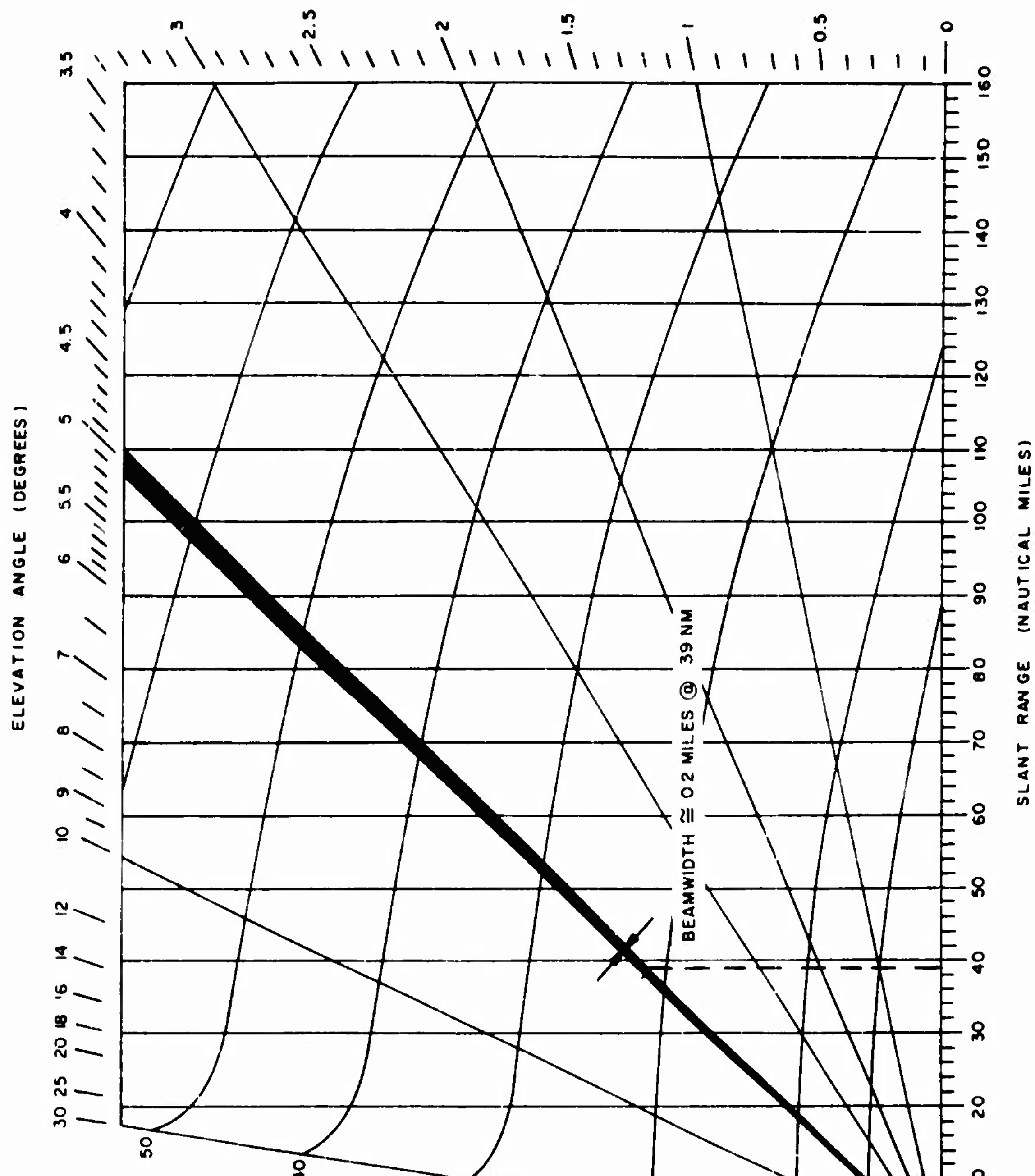

Figure 2-14. Geometry of Typical Earth Station Antenna (Beamwidth = 0.2°, Elevation Angle = 5°)

To avoid ground reflections and noise and to prevent blockage caused by surrounding terrain, most earth station antennas utilize elevation angles from a minimum of about 5° to a maximum of about 60°. Even at an angle as low as 5°, the horizontal distance through the beam is not appreciably greater than the orthogonal cross-sectional distance (see Figure 2-14). The beamwidth in nautical miles and the aircraft speed can, therefore, be used to approximate the time to traverse the beam. At a distance of 39 nmi the beamwidth of this typical earth station antenna is about 0.2 nmi (0.2°). An aircraft flying at 520 knots would be through the beam in about one second.

Since one second outages should be tolerable, fifth harmonic interference by this equipment type may be ignored.

The following listing identifies a variety of additional emitter types operating in this frequency category.

1. A large number (400-500) of emitters apparently used for short-haul point-to-point communications; emitters characterized by powers generally less than 10 watts coupled with 30 to 40 dB gain antennas.
2. A few ECM emitters used for electronic warfare training.
3. A few emitters used for open field RF measurements.
4. One satellite emitter.
5. A few 5 and 10 kW communications emitters coupled to 2 dB omni-directional antennas.

None of these emitters are expected to cause CAS receiver interference because of either low transmitter power or low antenna gain.

SUMMARY

Television emitters operating on five domestic and four European channels may cause CAS receiver performance degradation when CAS-equipped aircraft are below an altitude of 5000 feet and within 30 nautical miles of the emitter. Since enroute commercial aircraft normally maintain altitudes above 5000 feet, enroute degradation is not anticipated. Aircraft approaching or departing terminals necessarily fly below this altitude. Two television emitters, WNYE-TV (New York, New York) and WWRO-TV (Newark-Asbury Park, New Jersey), may degrade the performance of CAS receivers aboard aircraft approaching or departing New York area terminals.

Mainbeam illumination of CAS-equipped aircraft by second sub-harmonic tropospheric scatter emitters and by narrowband and wideband emitters operating in the CAS RF passband may cause CAS receiver performance degradation at separation distances within 243 nautical miles (radio-line-of-sight at a 40,000-foot altitude). Tropospheric scatter emitter sidelobe illumination is not expected to cause degradation unless the CAS-equipped aircraft is within fifteen degrees of the TS antenna boresight. Sidelobe illumination by narrowband and wideband emitters may, respectively, cause degradation at distances as great as 61 and 12 nautical miles.

When operated at frequencies within the CAS RF bandpass, emitters used for test and evaluation, electronic warfare training or ECM system evaluation may cause CAS receiver performance degradation.

The following table, TABLE 2-11, is based on the CAS interference threshold and the minimum distance discussed in the RADAR ALTIMETER INTERFERENCE subsection.

TABLE 2-11

TAU 2 PROTECTION CRITERIA

Altimeter	Minimum Distance Criteria (feet)
AN/APN-133A	700
AN/APN-155A	600
AN/APN-159A	71,000
IFD GAR	700
Bonzer TRN-70	300

Spurious response interference in the third harmonic passband of the CAS preselector is a function of the passband bandwidth and the CAS receiver intermediate frequency. To prevent this interference, the third harmonic passband bandwidth should be less than the ideal bandwidth shown in Figure 2-9. The choice of a 30 MHz IF coupled with no preselection may result in degradation at separation distances within 243 nautical miles for third harmonic TS emitters and out to 15 nautical miles for third harmonic, short-hop, point-to-point emitters.

Fifth harmonic satellite ground terminal emitters will not degrade CAS receiver performance unless the CAS-equipped aircraft flies through the emitter mainbeam. Beam traverse times will normally be less than one second. Other fifth harmonic emitters are not expected to cause CAS receiver interference because of their low effective radiated power.

SECTION 3

ANALYSIS OF FUTURE SYSTEMS

This section consists of two basic subsections. The first subsection discusses the mutual interference between CAS and two typical near-future ATC/S systems. The second subsection is a brief analysis of the potential interference to CAS from a number of possible in-band future systems.

The equipments analyzed here are described in APPENDIX A, which also contains the major system parameters that were used in this analysis. In most cases, feasibility studies and proposals were the only available system documentation for synthesizing transmitter and receiver models for these future systems.

DIOSCURES AND NORTH ATLANTIC SATELLITE SYSTEMS

Interference analyses between CAS and two near future ATC/S systems constitute this subsection. These two ATC/S systems are the Dioscures air traffic control satellite system and the North Atlantic Aeronautical Satellite System. The characteristics of the equipment for these systems are contained in APPENDIX A.

Interference From CAS

Collocated Dioscures ATC/S Receiver. The CAS range/range rate transmission will produce an IF output pulse of 125 μs in the Dioscures receiver. The 125 μs pulse will be followed by two 5 μs IF output pulses caused by the CAS altitude pulse. These receiver IF output pulses will occur every three seconds, and will be caused by the alternating transmissions of the upper and lower CAS antennas. Pulses due to the upper CAS antenna transmissions occur every six seconds; pulses due to the lower CAS antenna transmissions also occur every six seconds.

The signal-to-interference (S/I) ratios, (Dioscures desired signal, CAS interfering signals) for varying Dioscures-CAS antenna separations are presented in TABLES 3-1 and 3-2. These S/I values consider coupling between the CAS and Dioscures antennas mounted on two types of aircraft, the Boeing 707 and Boeing 747. Coupling values were computed in accordance with a procedure described in Reference 7. These coupling values are a function of both the loss due to the linear distance between the antennas as measured along the longitudinal axis of the aircraft and the curvature loss. Since the ATC/S antennas are located

TABLE 3-1

S/I AT ATC/S RECEIVERS DUE TO EMISSIONS OF LOWER CAS ANTENNA (ALL S/I RATIOS IN dB)

Separation Between CAS and ATC/S Antennas (Ft)	Fast Transition (40 ns) CAS 1 μs Pulse				Slow Transition (400 ns) CAS 1 μs Pulse				CAS Altitude Pulse			
	Dioscures		N. Atlantic Voice **		Dioscures		N. Atlantic Voice **		Dioscures		N. Atlantic Voice **	
	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C
10	6	24	14	31	28	46	36	53	29	47	34	51
50	−4	16	8	23	18	38	30	45	19	39	28	43
100	−8	9	6	19	14	31	28	41	15	32	26	39
150	*	6	*	17	*	28	*	39	*	29	*	37

* N/A, 707 aircraft are 145 to 153 ft. in total length.
** To obtain N. Atlantic Surveillance S/I values, subtract 4 dB.

TABLE 3-2

S/I AT ATC/S RECEIVERS DUE TO EMISSIONS OF UPPER CAS ANTENNA (ALL S/I RATIOS IN dB)

Separation Between CAS and ATC/S Antennas (Ft.)	Fast Transition (40 ns) CAS 1 μs Pulse				Slow Transition (400 ns) CAS 1 μs Pulse				CAS Altitude Pulse			
	Dioscures		N. Atlantic Voice **		Dioscures		N. Atlantic Voice **		Dioscures		N. Atlantic Voice **	
	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C	707 A/C	747 A/C
10	−59	−59	−30	−27	−37	−37	−8	−5	−36	−36	−10	−7
50	−45	−45	−19	−18	−23	−23	+3	+4	−22	−22	+1	+2
100	−39	−39	−14	−13	−17	−17	+8	+9	−16	−16	+6	+7
150	*	−35	*	−9	*	−13	*	+13	*	−12	*	+11

* N/A, 707 Aircraft are 145 to 153 ft. in total length.
** To obtain N. Atlantic Surveillance S/I values, subtract 4 dB.

on the upper surface of the aircraft, the transmission path between it and the lower CAS antenna is along the fuselage circumference. As the linear distance between these antennas increases, the curvature loss decreases. However, curvature loss decreases at a faster rate than the increase in linear-distance path loss. Thus, interference path loss between antennas on opposite sides of an aircraft decreases as linear distance increases. In the case of CAS upper antenna transmissions, the propagation path is more straightforward, and the greatest separation produces the least interference.

It may be seen in TABLES 3-1 and 3-2 that the upper CAS antenna emission is the predominant contributor to interference. The received power from the lower CAS antenna emission seldom exceeds the received power level of the desired signal.

The duration of the CAS pulses in the Dioscures receiver is too short to affect the decoding of the desired signal, but may be sufficient to cause the Dioscures receiver to lose phase lock with the desired signal. An interference study of phase-lock loops (Reference 8) shows that a negative S/I ratio should cause loss of lock during a 125 μs period if the phase-lock loop bandwidth is greater than approximately 800 Hz; the Dioscures phase-lock loop bandwidth specification is not available. Loss of receiver phase-lock will cause significant degradation of the Dioscures system because of the 0.67 seconds required to regain phase-lock and demodulator synchronization.

Collocated North Atlantic ATC/S Receiver. The CAS range/range rate transmission will produce an output pulse of 153 μs at the voice/data IF output and a 220 μs pulse at the surveillance IF output. Several hundred microseconds later, the CAS altitude pulse will produce a 33 μs and a 100 μs pulse at the voice/data and surveillance IF outputs, respectively. These IF output pulses will occur every three seconds, with the transmissions of the upper and lower CAS antennas alternately producing them. The ratios of the desired North Atlantic signal to the CAS interference are presented in TABLES 3-1 and 3-2 and indicate that the upper CAS antenna emission is the prime interference source. The interference power due to emissions of the lower CAS antenna does not exceed the desired signal in any case.

The duration of the CAS pulses in the North Atlantic receiver is too short to prevent proper operation of this system, although nuisance interference to voice reception may be noticeable every 6 seconds. Loss of phase lock is possible; a negative S/I ratio should cause loss of lock during a 220 μs period if the phase-lock loop bandwidth is approximately 450 Hz or greater. If loss of lock occurs, the amount of degradation will be dependent upon the time required to regain phase lock. Neither loop bandwidth nor time to lock are available for this system.

ATC/S Receivers Aboard Other Aircraft. The interference criteria discussed in the previous subsection can be applied directly to the situation where ATC/S receivers are aboard other aircraft. In this case the coupling path between the ATC/S and CAS antennas is not around the aircraft fuselage but through the air. Since the ATC/S is to be used on transoceanic aircraft, the flight corridor separations determine the air coupling paths. Both present and future corridor separations have been considered in this study.

Because of the transoceanic flight paths of commercial aircraft, CAS to ATC/S interference is possible when both the CAS-equipped aircraft and the victim aircraft are within the same flight corridor and at different altitudes. No interference is predicted between corridors or between co-altitude aircraft in the same corridor.

If the slow transition CAS pulse is used, the present minimum aircraft separation of 2000 feet will be sufficient to prevent interference to either the Dioscures or the North Atlantic System.

If the fast transition CAS pulse is used, and aircraft separation is 2000 feet a negative S/I ratio will occur at the IF output of both the Dioscures and North Atlantic receivers. As stated previously, the receiver degradation will be dependent upon the receiver phase-lock loop bandwidth.

Interference to CAS

Both ATC/S systems are allocated frequencies from 1642.5 to 1660 MHz. This allocation provides 27.5 MHz frequency separation between either ATC/S and the CAS frequency of 1615 MHz. At this frequency separation, only the spurious emissions from either ATC/S may cause interference. Figures A-4 and A-5 show synthesized spectrums for these transmitters. The spurious emissions are shown to be nominally 60 dB down from the carrier power level as a worst-case. Antenna placement for the Dioscures system, as discussed in APPENDIX A, is at the front portion of the aircraft vertical stabilizer. The North Atlantic ATC/S antennas are mounted 30° to 40° off the top centerline on either side of the aircraft.

TABLE 3-3 shows the required path loss to ensure that the received spurious transmissions from either ATC/S system will be less than the interference threshold outlined in APPENDIX B. Mainbeam coupling was used for the aircraft-to-aircraft case. Antenna sidelobe coupling was used where both CAS and ATC/S were mounted on the same aircraft.

TABLE 3-3

REQUIRED ATC/S-TO-CAS PATH LOSS

	Dioscures	North Atlantic ATC/S
Aircraft-to-Aircraft	63 dB	59 dB
Same Aircraft	50 dB	50 dB

Since ATC/S will only be used for transoceanic flights, the aircraft corridor and minimum elevation separations will determine the degree of interference to CAS. The present lateral separation between corridors is 120 nautical miles and future plans call for reducing this to 30 or 60 nautical miles when ATC/S is used. Present minimum separation for aircraft within the same corridor is 30 minutes of longitude with 5 minutes of longitude specified for the future. Both present and future altitude separations are 2000 feet. Since the aircraft-to-aircraft interference case requires either 63 dB of path loss (60 feet) or 59 dB (40 feet), there will be sufficient path loss between aircraft with either the present or future transoceanic flight rules.

For the situation where both CAS and one of the ATC/S systems are collocated on the same aircraft, a minimum path loss of 50 dB is necessary. Only the Dioscures system can cause interference to CAS with this requirement. The upper CAS antenna and the Dioscures antenna must be separated by at least 16 feet to achieve this path loss. Since present plans are to mount the Dioscures antenna in the front portion of the aircraft vertical stablizer and the CAS upper antenna above the cockpit, there should be no interference with CAS operation.

INTERFERENCE FROM POSSIBLE FUTURE SYSTEMS

This subsection discusses the analysis of the interference effects to CAS from possible in-band future systems. These systems are proposed for maritime communications, aeronautical communications, and an aircraft landing system. APPENDIX A contains the description and specifications of each system considered. Feasibility studies and proposals were the only available system documentation for synthesizing transmitter characteristics for these systems.

Interference From Satellites

The proposed communication systems are to use satellites as relays in order to provide world wide coverage. In general, these satellites are to be in equatorial, geo-stationary orbits at a distance of 19,000 nmi. The highest satellite transmitter effective-radiated-power is 72 dBm. If there were no CAS receiver rejection to these off-tuned satellite transmissions, the received interference would be −115 dBm in the CAS IF. This power level is below the CAS interference threshold.

Maritime Satellite System (MARSAT)

It is anticipated that the MARSAT shipboard installation will have capabilities for transmitting one narrowband FM communication channel. This channel can carry either voice or low rate (100 words per minute) telemetry data at a bit rate of 75 bits per second. Due to this slow bit rate and large frequency separation from CAS of approximately 22 MHz, interference from MARSAT to CAS will appear as transmitter noise. In order to avoid interfering with CAS operation, a minimum separation of 300 feet should be maintained.

Applications Technology Satellites (ATS-F and ATS-G)

Only the transmissions between these satellites and aircraft which are part of the Position, Location, and Aircraft Communication Equipment (PLACE) experiment will be in the 1600 MHz frequency band. Two areas within the United States will be used for this experiment: Barstow, Nevada, and Rosman, North Carolina.

The aircraft transmitter will be capable of transmitting both a surveillance channel and a voice/data channel. A synthesized spectrum for the PLACE airborne transmitter is shown in Figure A-4.

Frequency separation between ATS-F or ATS-G and CAS will be 35 MHz. Due to this separation and the narrow transmitter spectrum, interference to CAS will appear as transmitter noise. The minimum distance which will attenuate this interference to the CAS interference threshold is 700 feet.

Fourth Generation Aeronautical Satellite System

This system is currently planned for the 1990s. At that time only one 25 MHz wide channel will be required to handle the anticipated air traffic. However, by 2010 another

channel will be required which will increase the spectrum usage to 50 MHz. As currently envisioned, the aircraft and one of the satellite links will use the 1600 MHz frequency band. Figure A-6 contains a synthesized spectrum of the aircraft up-link transmission; the broad spectrum is due to the biphase bit duration of 100 ns with a transition time of approximately 50 ns.

It is not known exactly what frequency the proposed aircraft transmitter will use; however, it was assumed that the center frequency of the two channels will be 1622.5 MHz and 1647.5 MHz. Transmissions on either channel will be within the CAS frequency band. This will produce a pulse of approximately 52 μs in the CAS IF for each aircraft-to-satellite transmission. This will be repeated every second since the aircraft in this satellite system are required to transmit every 1 to 1.3 seconds.

With the one channel configuration, the required path loss between the airborne ATC transmitter and CAS is 101 dB. With two channels, 128 dB of path loss will be required to attenuate the ATC signal to the CAS interference threshold. The following table shows the aircraft-to-aircraft distance necessary to achieve this loss, assuming mainbeam-to-mainbeam coupling between CAS and ATC/S.

Configuration	Distance
One Channel	1 nmi
Two Channels	19 nmi

The Signal Environment Model was used to analyze the interference effects within aircraft deployments. The same transmitter and receiver deployments were used as for the radar altimeter/CAS analysis. It was assumed that all aircraft in the transmitter deployment (189 aircraft) were equipped with CAS. The average number of aircraft for all receiver deployments was 42 aircraft. TABLE 3-4 shows the average of the interference effects for all computer runs.

Antenna placement of these two systems collocated on the same aircraft is critical. The only discussion for the Fourth Generation system in Reference 9 concerns the antenna location on a general aviation aircraft where the antenna is above the cockpit. Moreover, the upper CAS antenna is to be located in the same area. This configuration will result in extremely high interference power being coupled into the CAS receiver. Antenna placement for commercial airliners is not discussed in this reference; however, it may be possible to

TABLE 3-4

EXPECTED NUMBER OF INTERFERENCE PULSES PER SECOND

	Received Peak Power Level (dBm)				
	−90	−80	−70	−60	−50
One ATC/S Channel					
Average Pulse Count	0	0	0	0	
Highest Pulse Count	2	0	0	0	
Cumulative Number of Receivers	2	0	0	0	
Two ATC/S Channels					
Average Pulse Count	4	1	0	0	
Highest Pulse Count	7	3	1	0	
Cumulative Number of Receivers	41	27	4	0	

TABLE 3-5

INTERFERENCE TO INTERFERENCE-THRESHOLD RATIOS FOR CAS RECEIVER, IN dB

Separation Between CAS and ATC/S Antennas (Ft.)	Upper CAS Antenna				Lower CAS Antenna			
	One Channel ATC/S		Two Channel ATC/S		One Channel ATC/S		Two Channel ATC/S	
	707	747	707	747	707	747	707	747
10	55	55	82	82	−10	−38	17	−11
50	41	41	68	68	0	−20	27	7
100	35	35	62	62	4	−13	31	14
150	*	31	*	58	*	−9	*	18

* N/A, 707 Aircraft are 145 to 153 ft. in total length.

locate the ATC antenna at the aircraft tail. Even with this antenna placement, a 747 is too short to provide sufficient attenuation between the upper CAS and the ATC antenna. TABLE 3-5 shows the interference to interference-threshold ratios for various separation distances on both a 707 and a 747.

Improved Glide Slope System

If the improved glide slope system operates in this frequency band, it will be between 1557.5 and 1567.5 MHz. Plans are to utilize the existing 330 MHz equipment with up and down converters for 1600 MHz frequency band operation. Figure A-7 contains a synthesized spectrum for this system based on a two tone modulated carrier at 40% per tone.

Interference to CAS from the glide slope transmissions will appear as transmitter noise. This is due to both the fast spectrum fall-off of the transmitter and large frequency separation of 62 MHz between CAS and the glide slope. The minimum distance which will attenuate this interference to the CAS interference threshold is approximately 2800 feet.

SUMMARY

The following table is based on the CAS interference threshold and the minimum distances discussed in this section. These distances will provide sufficient path loss to attenuate the interference to a power level that is below the CAS interference threshold.

TABLE 3-6

MINIMUM AIRCRAFT-TO-AIRCRAFT SEPARATIONS FOR TAU 2 PROTECTION

System	Distance
To CAS from:	
ATC/S Systems	
Dioscures	60 ft.
North Atlantic	40 ft.
ATS-F & ATS-G	700 ft.
Fourth Generation	19 nmi
Others	
MARSAT	300 ft.
Glide Slope	2800 ft.

SECTION 4

SIGNAL ENVIRONMENT MODEL

The Signal Environment Model (SEM) is designed to be a general purpose computer program for determining the interference severity within a deployment of up to 2000 aircraft. Three basic inputs are needed for the SEM: deployment description, and transmitter and receiver equipment characteristics. Tabulated results of each computer run consist of the number of interference victims in specific interference bins. These bins are the total number of expected pulses received in designated power level categories. APPENDIX C contains an explanation of the required program inputs and their formats.

PROGRAM DESCRIPTION

SEM is based on the probability that any given deployment point represents an aircraft equipped with either a transmitter or a receiver. An expected pulse emission is computed for each transmitter type based on the user designated percentage of transmitters in the deployment, proportion of this percentage for each type, and pulse repetition frequency. An expected pulse reception factor is computed for the receiver based on the designated percentage of receivers in the deployment.

The entire deployment is sequenced through by assuming each deployment point is a receiver and that every other point is a transmitter with a PRF of the expected pulse emission. As the program selects each potential transmitter, the altitudes of both the receiver- and transmitter-equipped aircraft are compared. The altitude difference determines which gain regions are to be used for the interference coupling calculation. Comparison of both altitudes also determines whether the aircraft are in line-of-sight of each other. If they are, path loss calculations are based on freespace coupling; if not, a Smooth-Curve-Smooth-Earth (SCSE) model is used (References 10 and 11).

Freespace path loss is calculated using

$$\text{dB Loss} = 20 \log f + 20 \log D + 37.8 \qquad (4\text{-}1)$$

where:

f = frequency in MHz

D = slant range in nautical miles

An additional loss term is added to this formula at the option of the user. This term is a fading loss based on the Nakagami-Rice distribution (Reference 12) which is a shifted Rayleigh distribution and is calculated by

$$\text{fade loss (dB)} = 11\sqrt{-2\,\text{Ln}\,(1-x)} - C \qquad (4\text{-}2)$$

where:

Ln (1−x) = natural logarithm of (1−x)

x = uniformly distributed random variable on [0,1)

C = shift constant which is the mean of the Rayleigh distribution

The received power at the receiver antenna terminals is calculated using the appropriate path loss value, and the interference-to-noise ratio (INR) is calculated and stored. This procedure is repeated for the same receiver deployment point until all other deployment points have been considered as transmitters. Following this step, another deployment point is selected as a receiver and all other points assumed to be transmitters.

OUTPUT TABLES

Figure 4-1 shows an example of the SEM output for an airport-deployment computer run. The receiver deployment is from a NAFEC ATC/CAS test series and consists of 41 aircraft. The transmitter deployment is from photographs of a radar PPI located at Suitland, Md. These photographs were taken during May, 1971, and show 189 aircraft within a 200 nautical mile radius of the radar. Figure 4-1 (Sheet 4) shows the characteristics used for both the CAS receiver and a radar altimeter transmitter. Washington National Airport was used as the airport location of the receiver-equipped aircraft deployment at the coordinates shown in this table.

Figure 4-1 (Sheet 1) shows the first output table. Receivers are listed along the left side of this table, and each one is identified by printing the sequence number as the receivers appeared in the input. Expected pulse count distribution is shown to the right of each receiver. As an example, receiver number 228 can expect to receive 1183 PPS between 10 and 20 dB INR and 143 PPS between 20 and 30 dB INR.

Two other tables are generated which show the number of receivers within specific interference bins. These tables are formed by placing received INRs along the horizontal axis

and expected pulse counts along the vertical axis. The intersection of these two quantities within the table defines an interference bin. Figure 4-1 (Sheet 2) shows the first of these two tables which is the second output table.

This table is constructed by performing a count of all receivers which receive interference as defined by each interference bin. An example of this can be seen in Sheet 2 for the INR range of 10 to 20 dB. Here one receiver can expect to receive between 401 and 600 pulses per second. Adding all receivers in this column yields the total number of receivers (41) that will receive interference from 10 to 20 dB INR regardless of expected pulse count.

Sheet 3, the third output table, has the same type of axis display; however, the receivers are accumulated along the INR axis. Using the 10 to 20 dB INR range as an example, it can be seen that one receiver has an expected interference pulse count of 401 to 600 PPS at a power level of 10 dB INR *or greater.* Adding all receivers in this column yields the total number of receivers (41) that will receive interference of 10 dB INR or higher regardless of the expected pulse count. Column summations for both the exclusive and cumulative power bin tables are printed on a supporting data page of each printout.

Sheet 5 shows a plot of expected pulses for each INR level. Three pulse counts are displayed: the highest (H) received by any receiver at that power level, the mean (M), and the lowest (L) non-zero pulse count.

EXPECTED PULSE COUNT DISTRIBUTION FOR EACH VICTIM

INR (DB) RECEIVER	10	20	30	40	50	60	70	80	90	100	110	120	
228		1183.	193.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
209		1027.	78.	13.	0.	0.	0.	0.	0.	0.	0.	0.	0.
199		1066.	325.	52.	0.	0.	0.	0.	0.	0.	0.	0.	0.
190		1131.	325.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
216		1209.	390.	52.	0.	0.	0.	0.	0.	0.	0.	0.	0.
227		962.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
203		975.	143.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
207		1535.	468.	78.	0.	0.	0.	0.	0.	0.	0.	0.	0.
223		1769.	650.	312.	52.	0.	0.	0.	0.	0.	0.	0.	0.
193		1626.	234.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
205		1183.	91.	26.	26.	0.	0.	0.	0.	0.	0.	0.	0.
224		650.	104.	13.	0.	0.	0.	0.	0.	0.	0.	0.	0.
191		1157.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
197		1717.	520.	260.	52.	0.	0.	0.	0.	0.	0.	0.	0.
201		1535.	182.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
219		1899.	949.	260.	0.	0.	0.	0.	0.	0.	0.	0.	0.
220		1053.	325.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
195		1040.	91.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
222		1327.	182.	13.	0.	0.	0.	0.	0.	0.	0.	0.	0.
204		728.	78.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
198		1066.	78.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
221		1053.	312.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
210		1766.	585.	52.	0.	0.	0.	0.	0.	0.	0.	0.	0.
218		1626.	234.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
226		1144.	195.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
206		1288.	182.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
202		1053.	91.	39.	0.	0.	0.	0.	0.	0.	0.	0.	0.
196		1092.	286.	52.	0.	0.	0.	0.	0.	0.	0.	0.	0.
200		1183.	182.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
208		1899.	858.	273.	52.	0.	0.	0.	0.	0.	0.	0.	0.
192		1157.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
225		871.	130.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
230		988.	260.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
212		1105.	260.	65.	0.	0.	0.	0.	0.	0.	0.	0.	0.
213		1327.	104.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
214		1236.	104.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
229		728.	78.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
215		1743.	754.	260.	0.	0.	0.	0.	0.	0.	0.	0.	0.
194		981.	52.	26.	0.	0.	0.	0.	0.	0.	0.	0.	0.
211		1275.	234.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.
217		1301.	104.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure 4-1. Signal Environment Model Output (Sheet 1 of 5)

SELECTED DEPLOYMENT T/FCAS
EXCLUSIVE POWER BINS

EXPECTED PULSE COUNT	INR (DB) 10	20	30	40	50	60	70	80	90	100	110	120
1- 200		0	23	20	4							
201- 400		0	11	5								
401- 600		1	3									
601- 800		3	2									
801- 1000		4	2									
1001- 1200		16										
1201- 1400		7										
1401- 1600		2										
1601- 1800		6										
1801- 2000		2										

Figure 4-1. (Sheet 2 of 5)

SELECTED DEPLOYMENT T/FCAS
CUMULATIVE POWER BINS

EXPECTED PULSE COUNT	INR (DB) 10	20	30	40	50	60	70	80	90	100	110	120
1- 200		0	23	20	4							
201- 400		0	10	5								
401- 600		1	2									
601- 800		1	1									
801- 1000		2	1									
1001- 1200		7	3									
1201- 1400		4	1									
1401- 1600		10										
1601- 1800		2										
1801- 2000		2										
2001- 2200		1										
2201- 2400		1										
2401- 2600		1										
2601- 2800		2										
3001- 3200		2										

Figure 4-1. (Sheet 3 of 5)

DEPLOYMENT CHARACTERISTICS

DEPLOYMENT NAME	T/FCAS	
TYPE	AIRPRT	
NUMBER OF TRANSMITTER CANDIDATES	189	
NUMBER OF TRANSMITTERS (15)	2	
NUMBER OF RECEIVERS	41	

AIRPORT LOCATION OF DYNAMIC DEPLOYMENT

LATITUDE	LONGITUDE
38 51 0 N	77 2 29 W

RECEIVER	NAME	T/FCAS
	RECEIVER NOISE LEVEL (DBM)	-100
	ANTENNA GAINS (DB)	
	ABOVE	2
	BELOW	0
	MAIN	2
	MAINBEAM WIDTH (DEG)	180
	TUNING RANGE (MHZ)	
	FROM	1600
	TO	1656

TRANSMITTER(S)	EFFECTIVE POWER IN VICTIM BAND (DBM) FROM	TO	ANTENNA GAINS (DB) ABOVE	BELOW	MAIN	MAINBEAM WIDTH (DEG)	PRF ABOVE CHANGE-OVER ALT	BELOW CHANGE-OVER ALT	CHANGE-OVER ALTITUDE (FT)	TUNING RANGE (MHZ) FROM	TO	PROPORTION OF TRANSMITTER ENVIRONMENT
APN159	30	30	-78	2	12	50	4916	4916	1000	1630	1630	.25
APN159	34	34	-78	2	12	50	4916	4916	1000	1630	1630	.25
APN159	40	40	-78	2	12	50	4916	4916	1000	1630	1630	.25
APN159	41	41	-78	2	12	50	4916	4916	1000	1630	1630	.25

Figure 4-1. (Sheet 4 of 5)

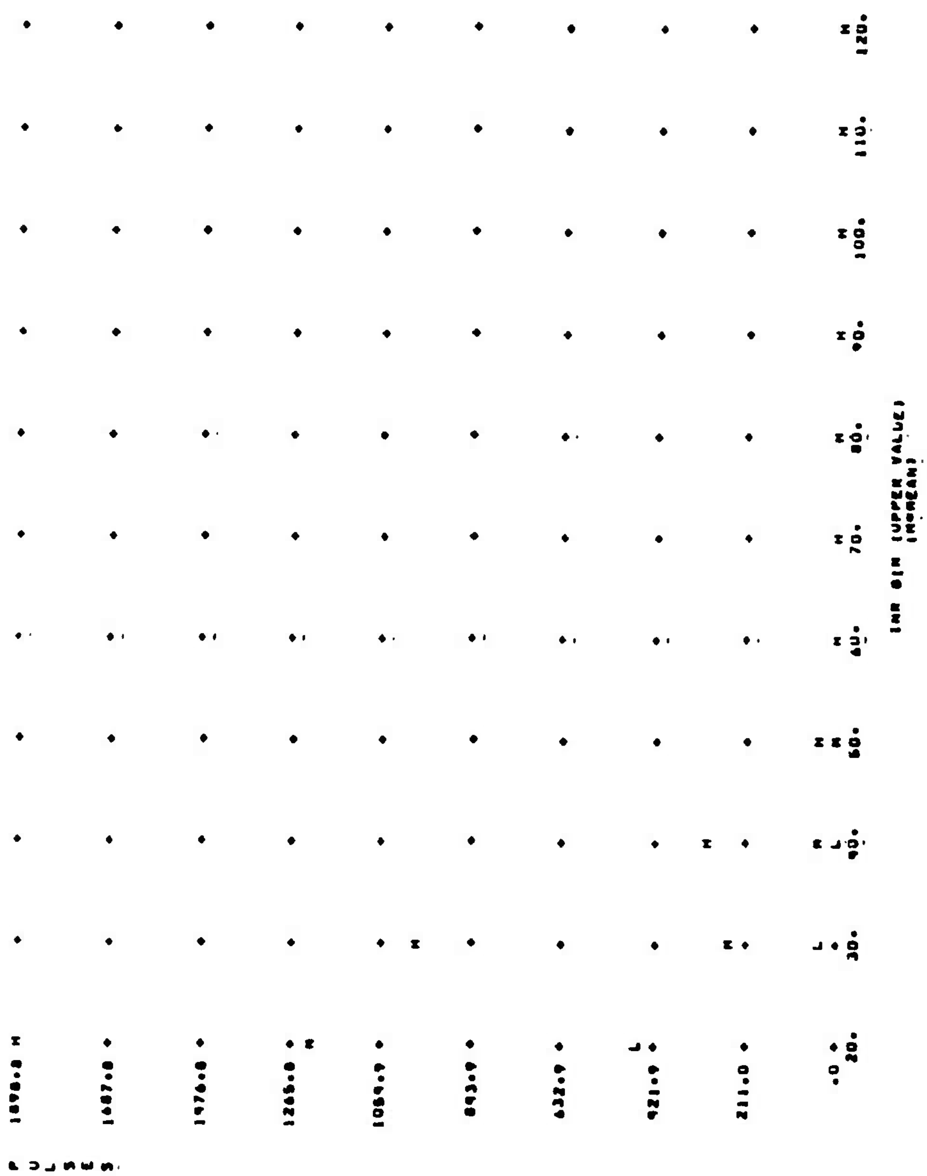

Figure 4-1. (Sheet 5 of 5)

SECTION 5

CONCLUSIONS

The following conclusions are based on the analyses presented in Sections 2 and 3.

EXISTING SYSTEMS

1. Television emissions on the following domestic and European channels may exceed the stated CAS receiver interference threshold when CAS equipped aircraft fly below 5000 feet and within 30 nmi of the TV emitter.

Domestic Channel Numbers: 24, 25, 68, 69, 70.
European Channel Numbers: 28, 29, 62, 63.

As an example, two television emitters, WNYE-TV (New York, New York) and WWRO-TV (Newark-Asbury Park, New Jersey), may degrade the performance of CAS receivers aboard aircraft approaching or departing New York terminal area.

2. Mainbeam illumination of CAS equipped aircraft by emitters in the following classes may cause the stated interference threshold to be exceeded at separation distances within radio line-of-sight (243 nmi at an altitude of 40,000 feet).

a. Tropospheric scatter communications emitters operating between 796 MHz and 811 MHz.

b. Narrow-band communications emitters in the CAS band (1592.5 MHz to 1622.5 MHz) operated by the U.S. Forces in Germany. Sidelobe illumination by these emitters can result in performance degradation within 61 nmi. Based on the mainbeam and sidelobe separation distances, a CAS receiver could conceivably be exposed to continual interference when flown within line-of-sight of these emitters.

3. Emitters operating in the CAS band used for test and evaluation (T-E) purposes, electronic warfare training or ECM system evaluation may be a source of CAS receiver interference. Coordination of T-E and ECM system operation will be necessary to operate the CAS.

4. The AN/APN-159A radar altimeter presents a serious interference threat to the CAS receiver.

5. Spurious response interference in the third harmonic passband of the CAS preselector is a function of the passband bandwidth and the CAS receiver intermediate frequency. To prevent this interference, the third harmonic passband bandwidth should be less than the ideal bandwidth shown in Figure 2-9.

6. Ground terminal emitters for satellite communications systems operating in the 7962.5 to 8112.5 MHz band will not degrade CAS receiver performance except during the period (generally less than one second) required for the aircraft to traverse the emitter mainbeam. Other emitters operating in this band are not expected to cause CAS receiver interference because of their low effective radiated power.

7. CAS receiver operation over parts of Europe may be affected by emitters operating in the 1535 to 1660 MHz frequency band. Portions of this band are allocated to the fixed service in 13 European countries. Wideband communications emitters in this service operating at frequencies within the CAS RF bandpass (1592.5 to 1622.5 MHz) may cause the stated interference threshold to be exceeded at separation distances within radio line-of-sight (243 nmi at a 40,000-foot altitude). CAS equipped aircraft in flight over Czechoslovakia may periodically fly in and out of interference.

FUTURE SYSTEMS

1. Future systems which represent potential interference sources to CAS:

   a. Aircraft transmitters of the Fourth Generation Aeronautical Satellite System.

   b. Improved Glide Slope System.

2. Systems that CAS can cause interference to:

   a. Dioscures ATC/S collocated on the same aircraft.

   b. North Atlantic ATC/S collocated on the same aircraft.

3. There are no interference problems to CAS from the future military systems analyzed in Volume II, with the possible exceptions of the Air Force PLRACTA/CNI and Navy ITAC systems.

APPENDIX A

SYSTEM CHARACTERISTICS

This appendix contains a brief description of the systems that either operate or are proposed to operate in the 1535 to 1660 MHz frequency band. Included in the description are equipment characteristics and interference criteria derivations. TABLE A-1 is a list of the systems, both proposed and existing, that were considered in this analysis. Since the characteristics of the FAA aeronautical satellite system were not available at the time of this analysis, official United States proposed systems for the 1970s are not included. However, the North Atlantic Aeronautical Satellite System was included in this analysis as a representative system for either the Atlantic or Pacific Oceans.

In addition to the Air Traffic Control/Satellite (ATC/S) systems listed in TABLE A-1, two other unclassified systems were discovered during the literature search for this project. These systems are:

1. Aircraft Satellite Navigational System formulated by NASA, FAA, ATA, ICAO and scheduled for the 1970s.
2. NASA Navigation/Traffic Control Satellite scheduled for the late 1970s.

Neither of these systems are sufficiently defined to merit their inclusion in this analysis.

COLLISION AVOIDANCE SYSTEM (CAS)

The Collision Avoidance System (CAS) is based upon very accurate time synchronization of all participating aircraft. This synchronization enables all aircraft (a maximum of 2,000) within radio communications range to transmit their relative range, range rate, and altitude to every other aircraft in the CAS environment. All transmissions are accomplished during one 3-second time period called an "epoch," which is divided into 2,000 equal time slots of 1500 μs duration. Each aircraft is assigned a time slot during which it transmits a synchronized burst of RF energy; all other aircraft use the burst to measure the range between themselves and the transmitting aircraft as well as the closing range rate.

Other information such as altitude, aircraft identification, and requests for time synchronization are transmitted by means of phase and pulse position modulation of the RF signal. Each aircraft will transmit this information during its assigned time slot and listen

TABLE A-1

ANALYZED SYSTEMS

System Name	Estimated Deployment
ATC/S	
French CNES/SGAC Dioscures	1970s
North Atlantic Aeronautical Satellite System	1970s
NASA ATS-F	1973
NASA ATS-G	1975
Fourth Generation Aeronautical Satellite System	1990s
OTHERS	
Maritime Satellite System	1970s
Improved Glide Slope	1970s
Radar Altimeters	Existing
Collision Avoidance System	Early 1970s

during all other time slots. This whole procedure is repeated every three seconds, or once each epoch. Alternate epochs differ from one another only in that during odd epoch periods, very accurate master ground stations will provide the time synchronizing signals. While during even epoch periods, the aircraft will provide the synchronization signals among themselves.

Each aircraft will be provided with two antennas: one on top and one beneath the plane. One will be used for transmissions and the other is used for reception. Generally, their functions will be switched every epoch in order to minimize the time during which the body of the aircraft will block the direct propagation path between two aircraft.

A threat evaluation is made of each received CAS signal. This evaluation can result in one of two indications to the aircraft pilot: advisory or command. Advisory indications inform the pilot that another aircraft is close, but not yet a collision threat. Command indications inform the pilot that another aircraft is close and on a collision course. For this analysis, the advisory indication boundary (Tau 2 boundary) will be used to determine the CAS signal level for interference power level comparisons. The Tau 2 boundary can be calculated using the formula in Reference 2 and is

$$R = 1.8 + 40\dot{R} \qquad \text{(A-1)}$$

where:

R = distance to boundary in nautical miles

$\dot{R}$ = aircraft closure rate in knots

A Tau 2 distance was calculated using two co-altitude supersonic aircraft approaching head-on at 1800 knots each. Therefore, at a 3600 knot closure rate Equation (A-1) yields a Tau 2 distance of 42 nmi. At this distance, the nominal received CAS signal strength at either aircraft will be −73 dBm at the antenna terminals. Since most aircraft cannot attain this speed, the Tau 2 signal strength is a minimum value, which is used in this analysis to provide at least Tau 2 interference protection for all aircraft.

The CAS pulse repertoire consists of six different pulses as listed in TABLE A-2 which are either biphase modulated or pulsed CW. Spectrum calculations using ECAC models, show that the biphase pulse and the altitude pulse are the extremes in spectral power density of all CAS pulses. Spectrums of the two pulses are shown in Figure A-1. Since the CAS circuitry

TABLE A-2

CAS CHARACTERISTICS

Frequency		1600, 1605, 1610, 1615 MHz	
Transmitter Power		62 dBm	
Antenna Gain		2 dBi*	
RF 3 dB Bandwidth		30 MHz	
IF 3 dB Bandwidth		2 MHz	
Receiver Noise		– 100 dBm	
Receiver Threshold		– 93 dBm	
Tau 2 distance for aircraft at 1800 knots		42 nmi	
Tau 2 CAS Signal Strength		– 73 dBm	
Pulses	Time Duration (μs)	Rise Time (μs)	Fall Time (μs)
Biphase			
planned	1	0.4 ± 0.1 (transition)	
optional	1	0.04 (transition)	
Altitude (PO)			
normal mode	25.6, + 0.4, – 0.2	0.3 ± 0.1	0.3, + 0.2, – 0.1
back-up mode	16.4, + 0.4, – 0.2	0.3 ± 0.1	0.3, + 0.2, – 0.1
Back-up mode warning (PO) and maneuver pulse	8.0, + 0.4, – 0.2	0.3 ± 0.1	0.3, + 0.2, – 0.1
Synchronization reply (PO)	1.6, + 0.4, – 0.2	0.3 ± 0.1	0.3, + 0.2, – 0.1

* Decibels relative to air isotropic radiator.

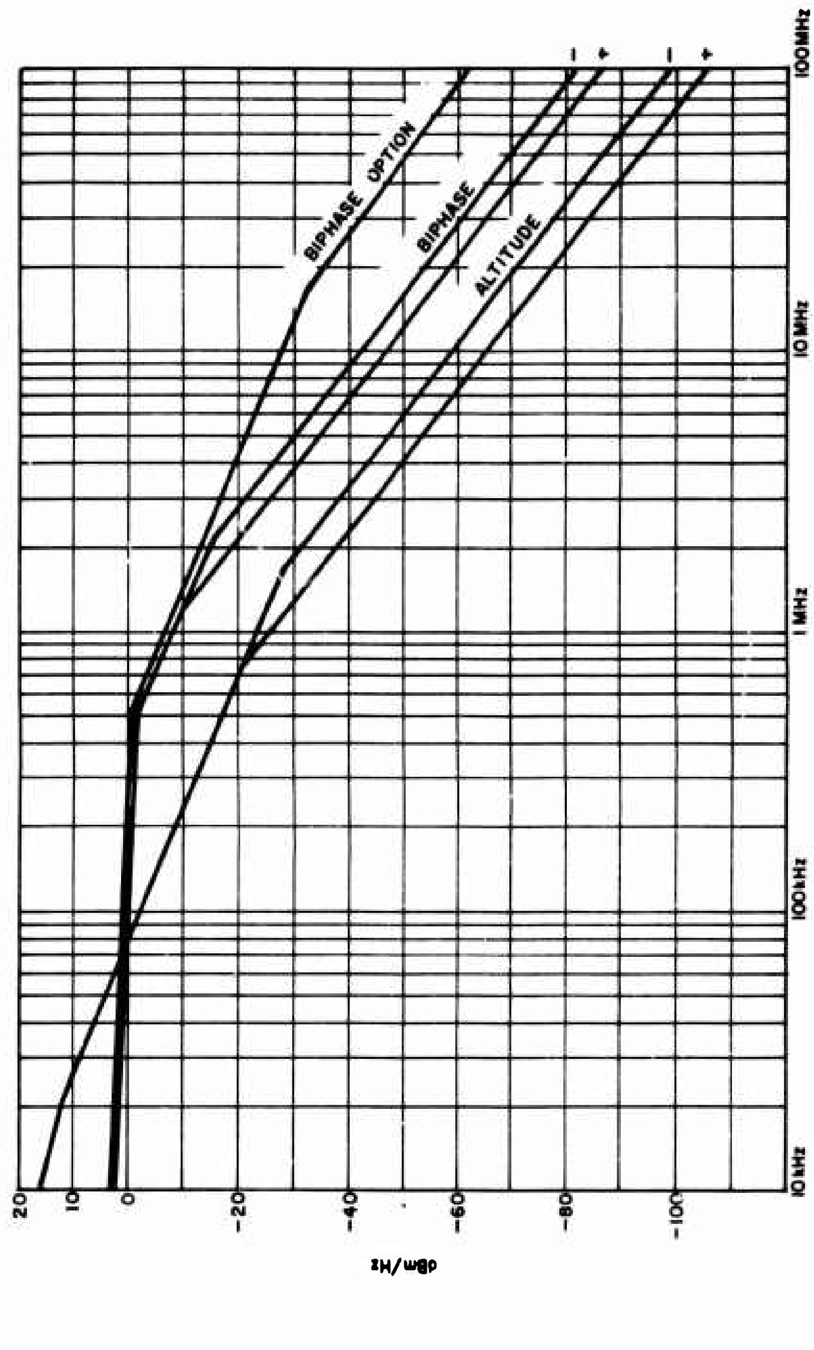

Figure A-1. CAS Altitude and Biphase Spectral Power Densities

can accommodate a biphase transition time as fast as 40 ns, two biphase spectrums are shown in this figure: one for the presently planned transition time (400 ns) and one for the 40 ns transition time. Time domain tolerances for both the altitude pulse and the 400 ns biphase have been considered in the spectrum calculations and are shown in this figure.

RADAR ALTIMETERS

There are four types of military and two types of civilian altimeters that operate in the 1600 to 1660 MHz frequency band. These altimeters are as follows: AN/APN-110 (), AN/APN-133A, AN/APN-155A, AN/APN-159A, Bonzer TRN-70, and In Flight Devices Ground Avoidance Radar (IFD GAR). Of these altimeters, only the AN/APN-110 () is not in use today according to reports from all military branches to ECAC. TABLE A-3 lists the characteristics of the altimeters used in the CAS/Radar altimeter interference tests, and Figures A-2 and A-3 show the calculated spectrums of these altimeters.

AIR TRAFFIC CONTROL/SATELLITE SYSTEMS (ATC/S)

The basic concept of all proposed ATC/S systems is the provision of communication, navigation, and location of aircraft. In these systems, synchronous equatorial satellites will relay information between aircraft and ground stations. Frequencies ranging between 900 MHz to 5100 MHz have been proposed for various links of the proposed systems. Only systems that may operate in the 1535 to 1660 MHz frequency band were considered in this analysis in order to determine their compatibility with CAS. Systems in this band will use frequencies between 1642.5 MHz and 1660 MHz for aircraft-to-satellite links and between 1540 MHz and 1592.5 MHz for satellite-to-aircraft links.

Numerous studies are available concerning the requirements of an ATC/S. Most of these studies give only general technical characteristics or list alternative characteristics for the postulated systems. Because of the extremely vague ATC/S situation, only two systems were chosen for a brief two-way interference analysis with CAS. These two systems are the North Atlantic Aeronautical Satellite System (Reference 13) and the Dioscures Project (Reference 14). For all remaining proposed ATC/S systems, only their interference potential to CAS has been analyzed. Since the characteristics of the FAA ATC/S were not available at the time of this analysis, official United States proposed systems for the 1970s are not included in this report. However, the North Atlantic Aeronautical Satellite System was included in this analysis as a representative system for either the Atlantic or Pacific Oceans.

TABLE A-3

RADAR ALTIMETER CHARACTERISTICS

	AN/APN-133A	AN/APN-155A	AN/APN-159A	IFD Ground Avoidance Radar	Bonzer TRN-70*
Approximate Quantity	400	1500	500	1500	2300
Power Output	50 dBm	29 dBm	63 dBm 56 dBm	30 dBm	27 dBm
Nominal Frequency	1641 MHz	1639 MHz	1632 MHz	1625 MHz	1630 MHz
PRF	49164 pps 9830 pps	CW sweep from 30 to 1500 Hz	4916 pps	136,400 pps	10,000 pps
Pulse Duration (at half amplitude points)	0.12 μs 0.5 μs	- - -	0.16 μs .048 μs	.03 μs	.05 μs
Antenna Gain*	8 dBi	10 dBi	12 dBi	≈ 8 dBi	6 dBi
Antenna Beamwidth*	60°	60° X 70°	55° X 36°	≈ 90°	90°

* As listed by equipment manufactures.

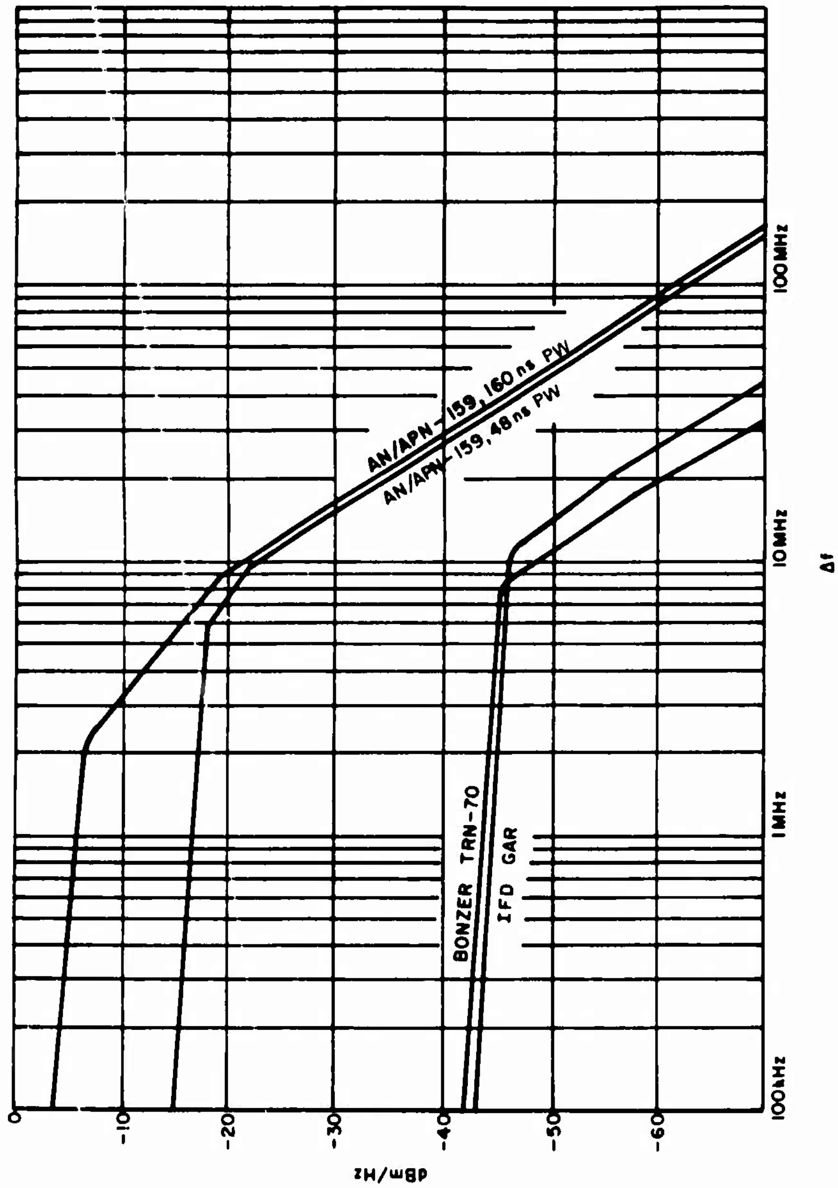

Figure A-2. Radar Altimeter Spectral Power Density

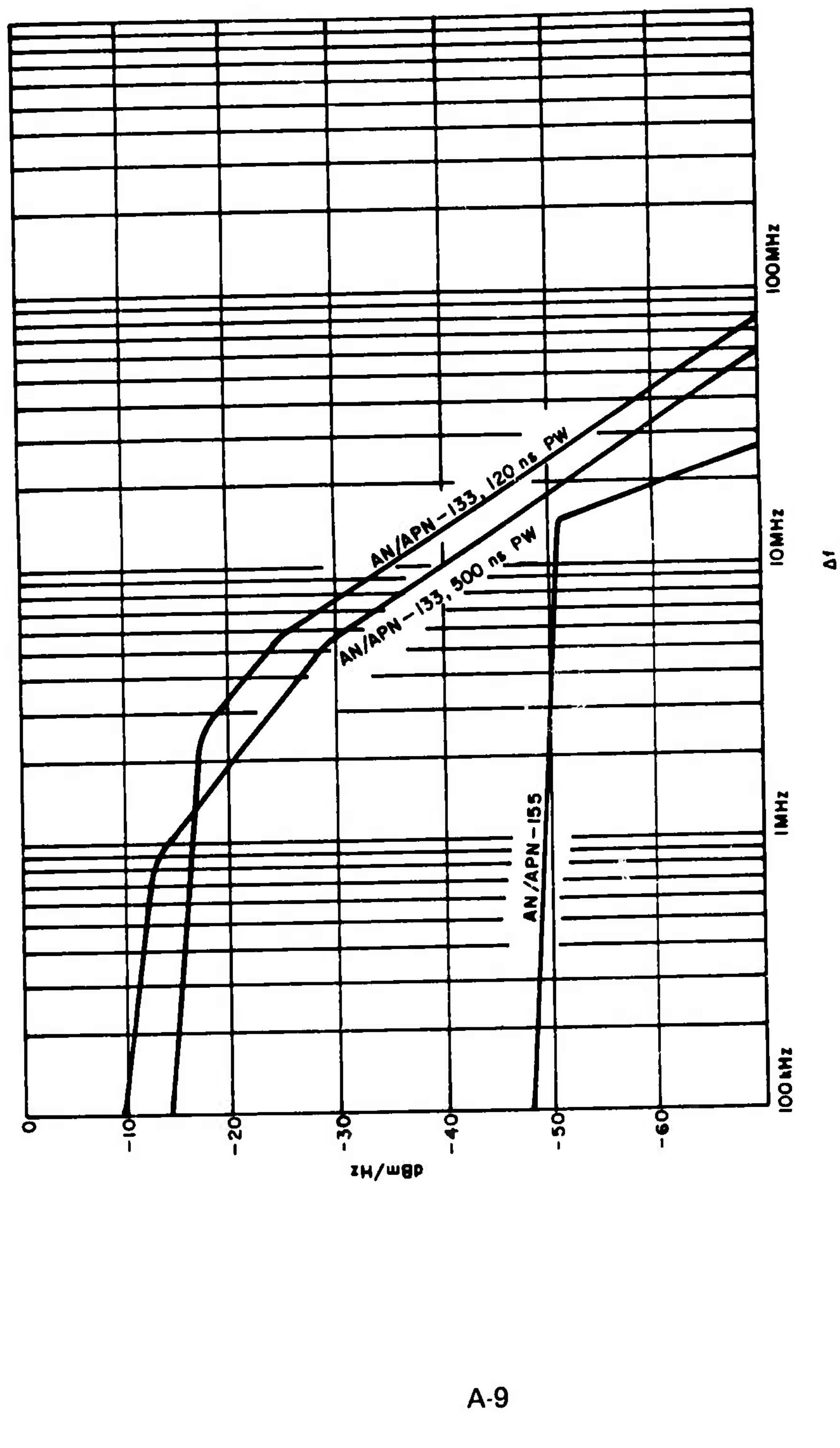

Figure A-3. Radar Altimeter Spectral Power Density

North Atlantic Aeronautical Satellite

Two satellites will be utilized for aircraft position determination (surveillance) and voice/data communications. Each satellite will be equipped with two repeaters: one for surveillance information and one for the voice/data links. Surveillance information is transmitted by the ground station in the form of a carrier which is phase modulated by five ranging tones and a data subcarrier. The satellite surveillance repeater transmits the carrier to the addressed aircraft, which responds by returning the received ranging tones along with altitude and identity data. The returned ranging tones are repeated by both satellites, and the ground station determines the aircraft's position by comparison of the two signals received.

The satellite voice/data repeater has a capacity of four simplex channels which may be used for voice or data. Each aircraft is equipped with a terminal capable of receiving and transmitting on one selected voice/data channel. A synthesized transmitter spectrum is shown in Figure A-4. This spectrum was used for both the North Atlantic system and the NASA PLACE experiment. The aircraft terminal uses narrowband FM modulation and phase-lock demodulator detection for voice/data communications. One aircraft receiver is used for simulataneous reception of the surveillance carrier and the voice/data channel.

Each aircraft will be equipped with two switch-selectable slot-dipole (3 dBi) antennas, mounted 30° to 40° off the top centerline on either side of the aircraft. The selected antenna will be used for transmission and reception of both surveillance and voice/data signals. The aircraft transmitter will operate in the 1640 to 1660 MHz band with an output power of 47 dBm. The aircraft receiver utilizes one antenna, one RF amplifier, and two IF amplifiers. One IF amplifier is used for surveillance signal processing and the other for voice/data signal processing. Receiver characteristics are provided in TABLE A-4.

Dioscures Project

Two satellites will be used for the Atlantic portion of this world coverage program. Aircraft position location methods are similar to those used in the North Atlantic Aeronautical Satellite proposal in that one signal is transmitted from the ground station to the aircraft and two return paths via two satellites are utilized. In this system, however, the location signal is Time Division Multiplexed (TDM) onto a phase modulated carrier rather than onto a tone modulated carrier.

Voice communications are digitized and multiplexed onto the same carrier as the location information for transmission to the aircraft. The overall multiplex rate is 90 kb/s

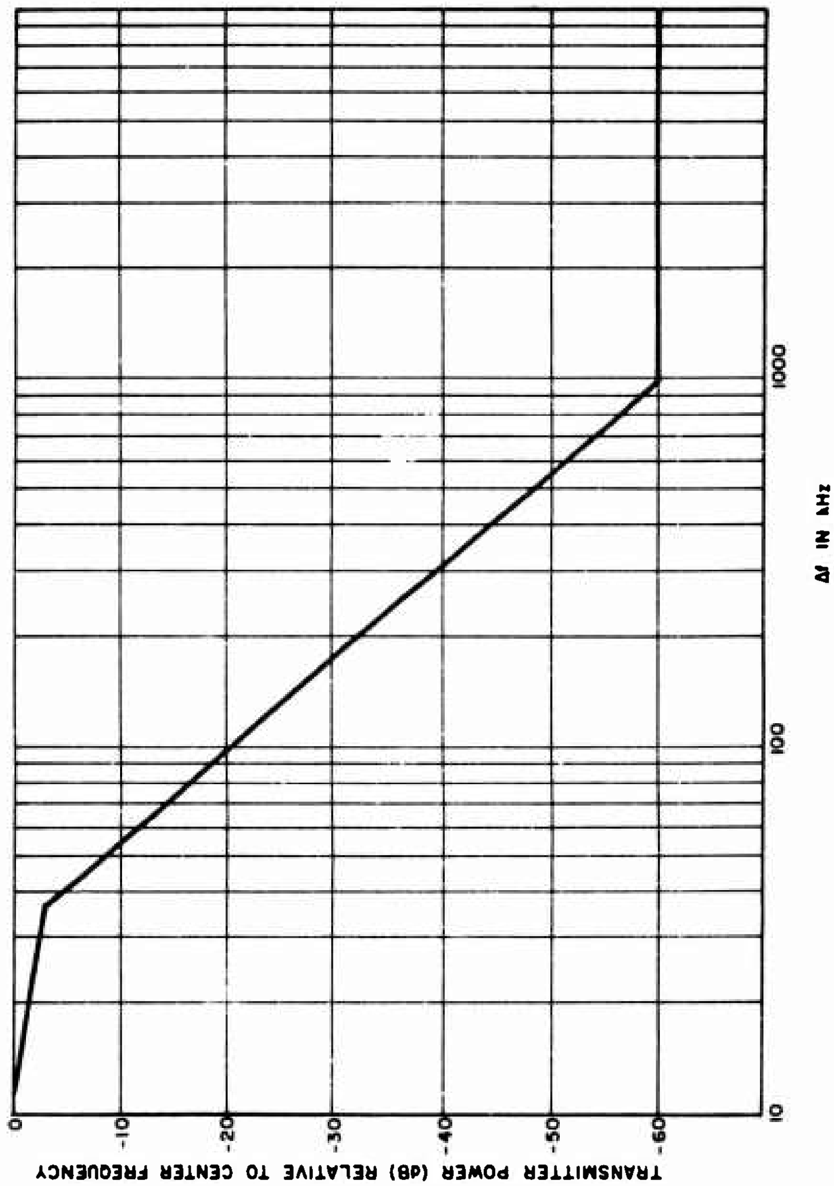

Figure A-4. Synthesized Airborne Spectrum of North Atlantic Aeronautical Satellite System and Place Experiment

and contains five channels which are sampled at a rate of 18 kb/s. One channel is used for time synchronization, three channels contain digital voice, and the fifth channel is sub-multiplexed with location and miscellaneous data. This carrier is relayed by either satellite to a phase-locked receiver in the aircraft. The aircraft receiver output is demultiplexed into the proper synchronization, voice, location, or data outputs.

For transmission, the aircraft communications operator chooses a voice channel based on channel occupation signals received via the multiplexed data. The operator's voice is digitized and multiplexed onto a carrier with digital data information. A separate carrier is utilized when location information is transmitted. A single aircraft transmitter transmits either the location multiplex to both satellites, or the voice/data multiplex to one satellite. Aircraft to satellite transmissions are in the 1640 to 1660 MHz band, and transmitter power is 43 dBm. Figure A-5 shows the synthesized spectrum used in this analysis.

The aircraft antennas to be used in the Dioscures system are phased arrays mounted in the front portion of the aircraft vertical stabilizer and inclined at 45°, one on each side. Each antenna, port or starboard, forms two beams which are electronically steered toward each satellite. The antennas are switch selectable and have a gain of approximately 10 dBi.

The satellite to aircraft power budget is provided in TABLE A-4.

TABLE A-4

ATC SATELLITE-TO-AIRCRAFT POWER BUDGETS (1550 MHz)

		North Atlantic	
	Dioscures	Voice	Surveillance
P_T (dBm)	44	49	40
G_T (dBi)	22	29	22
L_P (dB)	189	189	189
G_R (dBi)			
Mainbeam	10	3	3
Sidelobe	0	−4	−4
P_N (dBm)	−117	−125	−130
P_R (dBm)	−113	−108	−124
S/N (dB)	4	17	6

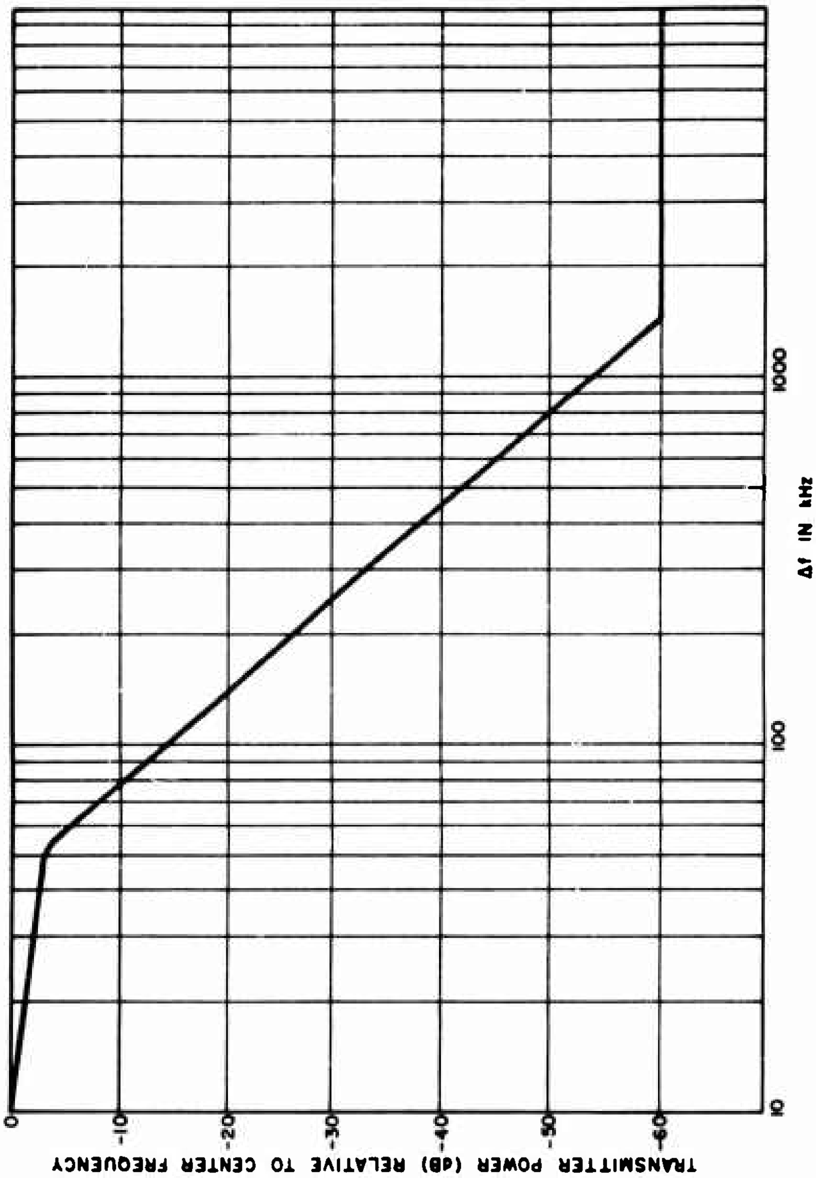

Figure A-5. Synthesized Airborne Spectrum of Dioscures System

P_T = transmitter output power

G_T = transmitter antenna gain above an isotropic antenna

L_P = propagation loss

G_R = receiver antenna gain above an isotropic antenna

P_N = receiver noise level

P_R = received power

S/N = signal to noise ratio

NASA APPLICATIONS TECHNOLOGY SATELLITES (ATS)

Two ATS series satellites are scheduled for launch during the early 1970s. The first satellite, ATS-F, will be launched during 1973; ATS-G, the second satellite, is scheduled for launch during 1975. Both of these satellites are expected to have a two year life. Among many other experiments, both these satellites will carry Position, Location and Aircraft Communication Equipment (PLACE). Only the PLACE experiment will use frequencies in the 1600 MHz band. References 15 and 16, contain descriptions of this experiment as outlined below.

PLACE will provide two-way voice and digital data communications between a limited number of aircraft and ground stations via a geosynchronous satellite. In the PLACE experiment, only the communication link between the aircraft and satellite will use the 1600 MHz frequency band. The ground station to satellite links will be between 5950 and 6350 MHz. TABLE A-5 lists the satellite-to-aircraft (down-link) transmitter characteristics, and the aircraft-to-satellite (up-link) transmitter characteristics are shown in TABLE A-6. The aircraft transmitter spectrum is shown in Figure A-4.

FOURTH GENERATION AERONAUTICAL SATELLITE SYSTEM

This system is postulated for use in the 1990s and is considered as candidate for the fourth generation of air traffic control systems. It will be used for accurate location, navigation and communication for aircraft over land and oceans. As presently envisioned

TABLE A-5

ATS DOWN-LINK POWER BUDGET

Satellite Transmitter	
Frequency	1550 MHz
Power	46 dBm
Antenna Gain	22 dBi
Effective Radiated Power	68 dBm
Path Loss	187 dB

TABLE A-6

ATS UP-LINK POWER BUDGET

Aircraft Transmitter	
Frequency	1650 MHz
Power	47 dBm
Antenna Gain	25 dBi
Effective Radiated Power	72 dBm
Path Loss	187 dBm

(Reference 9), both aircraft and satellites will use frequencies in the 1600 MHz band; however, no specific frequencies within this band have been announced.

Each aircraft will transmit on this up-link in one second intervals. These transmissions will consist of 51.5 μs of biphased information with bit lenghts of 100 ns.

The present goal for this system is to accommodate the peak air traffic expected by the year 2010 or a total of 100,000 aircraft. As presently configured, this system has an aircraft capacity of 50,000 aircraft per a 25 MHz wide channel, and, therefore, 50 MHz will be needed for the up-link in order to accommodate the 100,000 aircraft.

It is not known just how either the one or the two channel configurations will fit in the 17.5 MHz of spectrum assigned to aircraft up-link transmissions. TABLE A-7 shows the channel center frequencies used in this analysis; however, it should be noted that either configuration violates the frequency allocations as designated in the amended United States proposals to the Space WARC (Reference 1). The synthesized transmitter spectrum is shown in Figure A-6.

TABLE A-7

FOURTH GENERATION ATC/S AIRCRAFT TRANSMISSIONS

Frequency	
First channel center	1647.5 MHz
Occupied spectrum	1635 to 1660 MHz
Second channel center	1622.5 MHz
Occupied spectrum	1610 to 1635 MHz
Transmitter Power	64 dBm
Antenna Gain	4 dBi

IMPROVED GLIDE SLOPE SYSTEM

The improved glide slope system may be deployed during the 1970s. It currently has a provisional frequency assignment in the FCC Rules and Regulations (Reference 17) of 1557.5 to 1567.5 MHz.

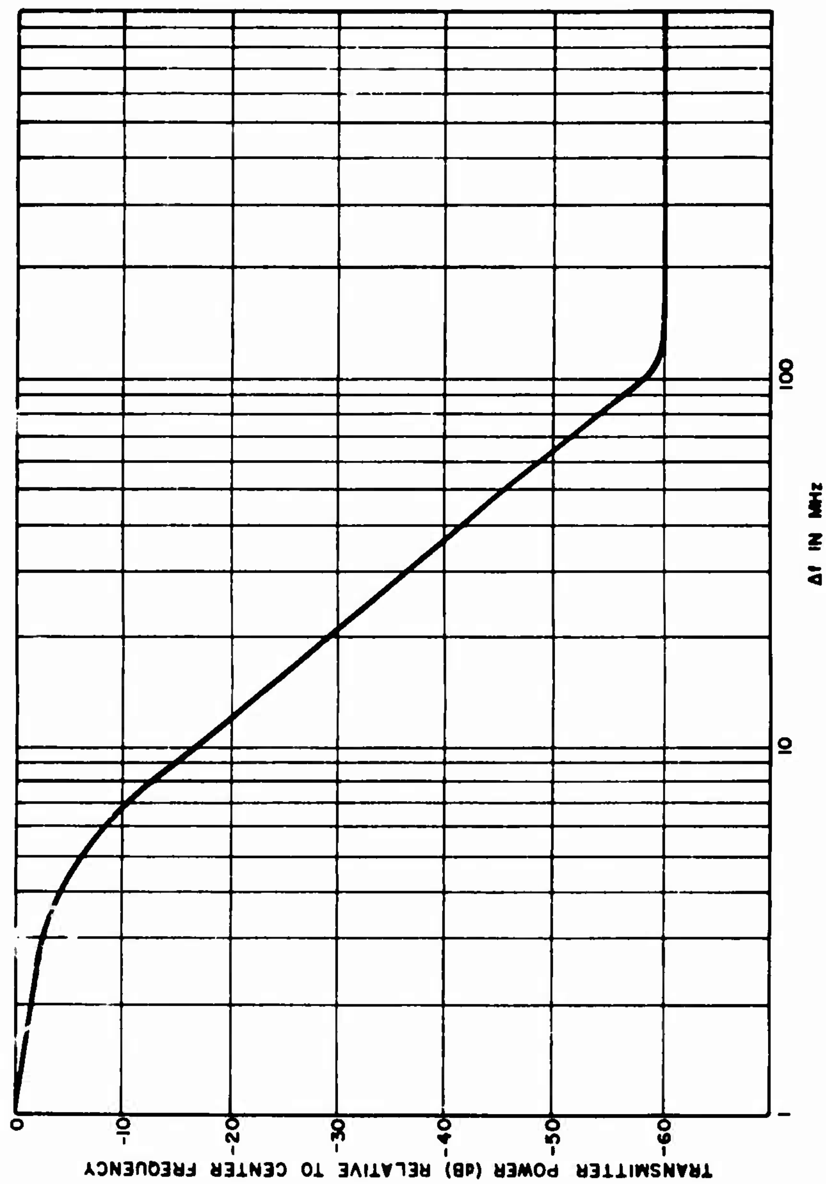

Figure A-6. Synthesized Fourth Generation Airborne ATC/S Transmitter Spectrum

Except for the operating frequency, this proposed system will be identical to the present glide slope system which operates between 328.6 and 335.4 MHz. System transmitter characteristics are expected to be as follows.

Frequency	1562.5 MHz
Power	34 dBm
Antenna Gain	25 dBi

A synthesized transmitter spectrum is shown in Figure A-7. This spectrum is based on a two tone modulated carrier at 40% per tone.

MARITIME SATELLITE SYSTEM (MARSAT)

Reference 18 is a study of maritime satellite requirements for the post 1975 era. Two frequencies are analysed in this study, 400 MHz and 1600 MHz, and a recommendation is made that the 400 MHz frequency band be used. For the purposes of this CAS interference analysis, it was assumed that MARSAT will operate in the 1600 MHz frequency band.

The purpose of MARSAT is to provide world-wide communications links for ship-to-shore, ship-to-ship, and shore-to-ship. It is anticipated that all ocean-going ships will use this communication system, and it is forecasted that the ships-at-sea population will be approximately 29,000 by 1980.

Reference 18 proposes that MARSAT be allocated two frequency bands at 1600 MHz. These bands are from 1535 to 1542 MHz for the down link and from 1637.5 to 1645 MHz for the up link. Possible equipment characteristics for these two links are shown in TABLE A-8. A synthesized spectrum for the shipboard transmitter is shown in Figure A-8.

TABLE A-8

MARSAT CHARACTERISTICS

Shipboard Transmitter	
Frequency	1637.5 to 1645 MHz
Power	52 dBm
Antenna Gain	10 dBi
Effective Radiated Power	62 dBm

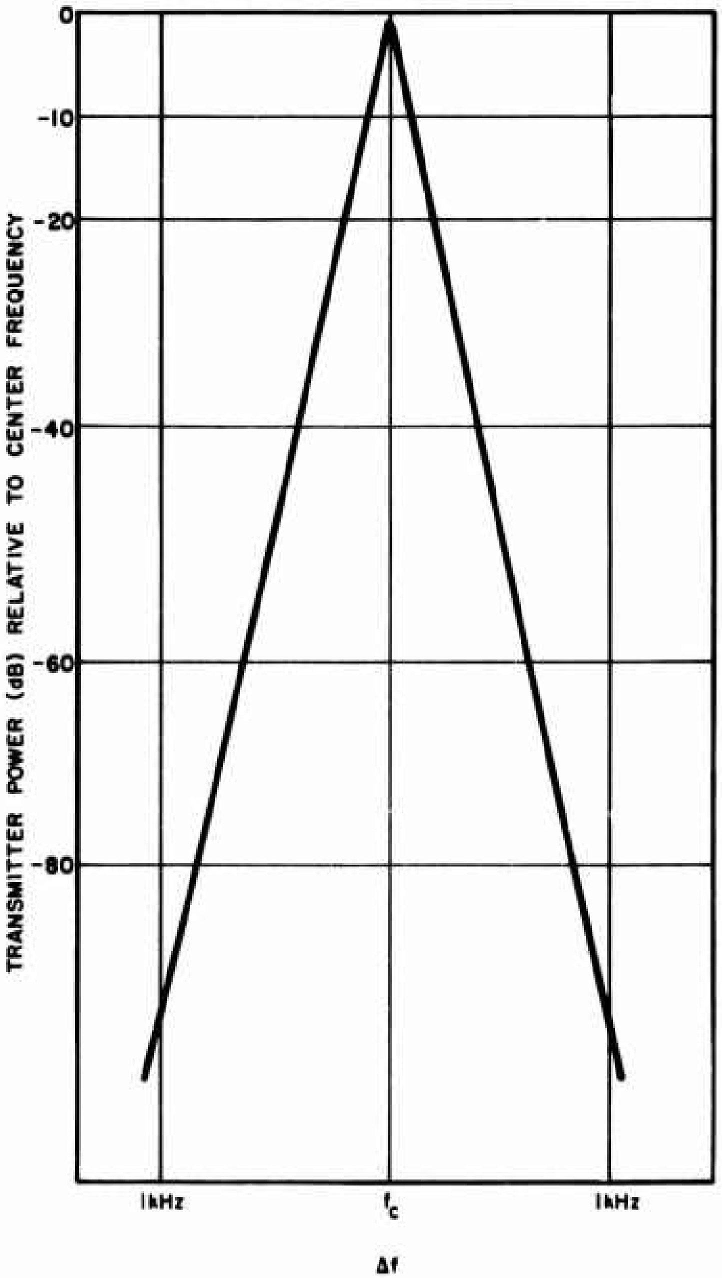

Figure A-7. Synthesized Improved Glideslope Transmitter Spectrum

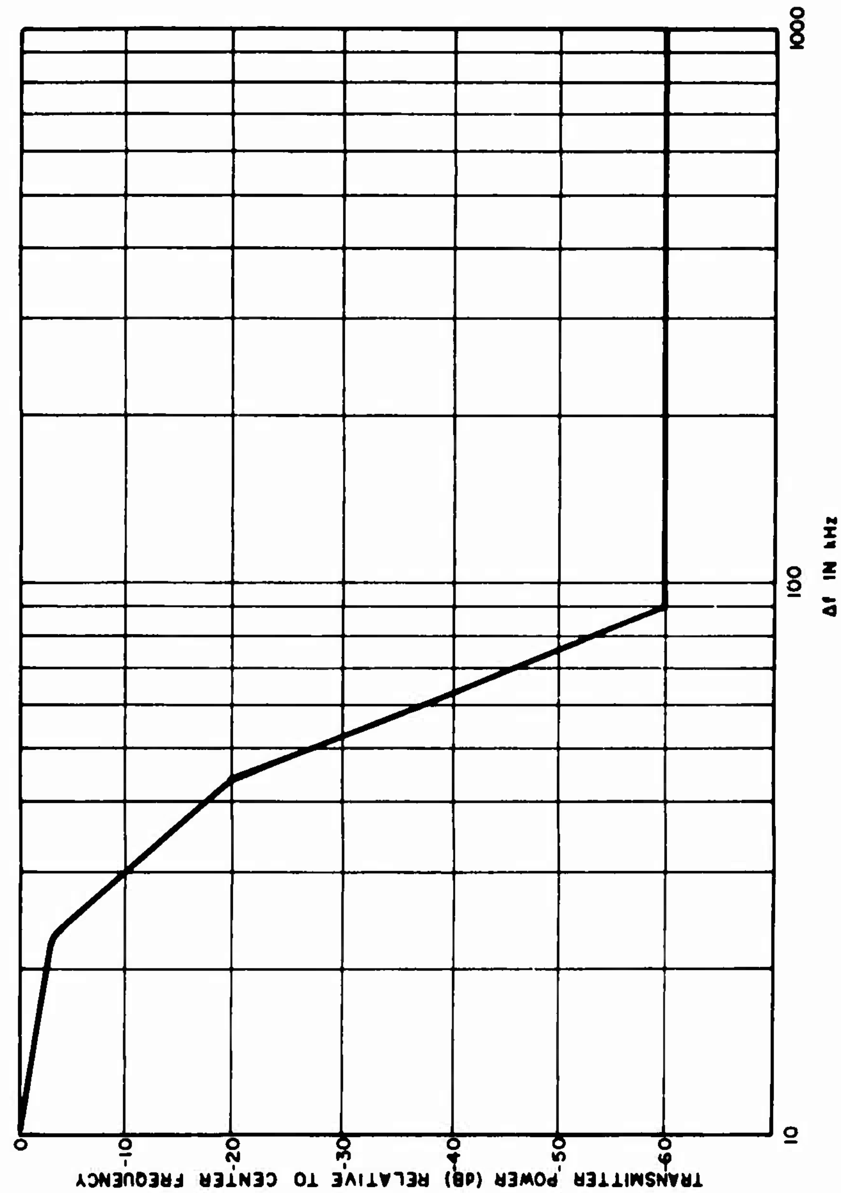

Figure A-8. Synthesized MARSAT Shipboard Transmitter Spectrum

APPENDIX B

CAS INTERFERENCE CRITERIA

TEST PROCEDURE

The CAS interference criteria used in this report is based on several CAS/radar altimeter interference tests conducted by the McDonnell Douglas Corporation. Test procedures consisted of coupling a CAS transmitter and radar altimeter transmitter into the CAS receiver. The CAS signal power was adjusted to the minimum level that produced a probability of detection of approximately 1.0. All altimeters were tuned to their nominal operating frequencies and the transmitter power was increased until the received CAS messages were clearly interfered with. The altimeter power at its tuned frequency was recorded, and the test procedure was repeated for each of the remaining three CAS frequencies.

CAS/RADAR ALTIMETER INTERFERENCE TEST

Except for the Bonzer TRN-70, all altimeters shown in TABLE A-3 have been used by the McDonnell Douglas Corporation for CAS/radar altimeter interference tests. These tests showed that altimeters caused severe interference to the CAS receiver. TABLE B-1 is a summary of the CAS receiver interference tests. The IFD Ground Avoidance Radar was tested separately from the other altimeters shown in this table. Throughout this separate test, the CAS desired signal was maintained at a constant –80 dBm for all CAS frequencies and the CAS receiver threshold was set at –86 dBm. CAS signal powers are shown in this table for all remaining altimeter tests. CAS threshold for these tests was set at –92 dBm. All altimeters were operated at their nominal frequencies and the peak interference power measured at these frequencies.

The last two data rows of this table show the mean value of peak and average interference power for each test. These power levels have been adjusted to show the actual interference power level in the 2 MHz CAS IF bandwidth. With the exception of the AN/APN-159A, all test data shows good correlation to the CAS interference power level. The apparent ultra-sensitivity of the CAS to the AN/APN-159A is not readily understandable, although it is possible that this altimeter has an excessively high level of local oscillator radiation. However, no data for this altimeter is available with which to explain why CAS was interfered with at such a relatively low power level.

TABLE B-1

CAS/RADAR ALTIMETER INTERFERENCE TEST DATA

CAS		APN-133A		APN-155A	APN-159A		CW	IFD GAR
Frequency	Signal Level	120 ns PW	500 ns PW	CW Altimeter	160 ns PW	48 ns PW	On-tune	CAS Signal = −80 dB
1600 MHz	−82 dBm	−27 dBm	−20 dBm	−28 dBm	−47 dBm	−53 dBm	−106	−46
1605 MHz	−85	−29	−24	−33	−51	−58	−110	−49
1610 MHz	−85	−34	−29	−45	−55	−64	−113	−52
1615 MHz	−84	−35	−29	−53	−57	−65	−108	−55
mean peak power level	−84	−80	−79	−80	−91	−97	....	−80
mean average interference power level	....	−102	−102	function of sweep time	−121	−133	−109 (σ = 3 dB)	−104

One other CAS receiver test was also made. This involved increasing the CAS desired signal and then increasing the altimeter power until the CAS received interference. This was done to 10 dB increments, and it was shown that approximately a 10 dB increase in interference power was necessary in order to maintain an interference condition. This linear relationship between interference and desired signal power levels held for all measured values.

CAS INTERFERENCE CRITERIA

Based on the linear relationship between interference and desired signal power level increases, a signal-to-interference ratio should be the interference criteria. Moreover, due to the inexplicable CAS sensitivity to the AN/APN-159A emissions and the good correlation among all other test data, the general interference criteria should not be based on the AN/APN-159A test results. Radar altimeter interference criteria should consist of two primary criteria: one for the AN/APN-159A, the other for all other altimeters. The latter, general altimeter criteria, will also be applicable to all transmitters other than altimeters. In the event that the CAS is designed with an AGC having a long time constant, an average power interference criteria should also be used.

Using the mean peak power and values shown in TABLE A-4, the AN/APN-159A caused interference at a signal-to-interference ratio (S/I) of +15 dB for the 48 ns pulse. The mean of the peak power S/I ratios of the remaining altimeters is −2 dB; however, for this report a peak power S/I of 0 dB was used. The mean value of the average power interference levels is −106 dBm. This then yields the ratio, of peak-signal to average-power interference level, of +22 dB.

The Tau 2 signal level, as discussed in subsectionCOLLISION AVOIDANCE SYSTEM (CAS) in APPENDIX A, was shown to be −73 dBm. Combining the Tau 2 signal level with the above interference ratios yields the following table of interference power levels used in this report.

TABLE B-2

CAS INTERFERENCE LEVELS

Transmitter Type	Peak Power	Average Power
AN/APN-159A	−89 dBm	−122 dBm
All other transmitters	−73 dBm	− 95 dBm

APPENDIX C

SIGNAL ENVIRONMENT MODEL PROGRAM INPUTS

DEPLOYMENT DESCRIPTION

Two types of deployment inputs can be used with the SEM. The first type is a static deployment consisting of both transmitters and receivers. The second type of input consists of two deployments, one of which is entirely composed of receivers, and the other deployment consists of potential transmitters. This second input type—or two deployment input – accommodates the airport deployments generated by NAFEC in the ATC/CAS simulation effort. Aircraft of the airport deployment are used as the receivers and any other deployment can be used as the potential transmitter deployment. The airport, and consequently the NAFEC deployments, can be positioned anywhere within or outside the geographical area covered by the transmitter deployment. This is done by entering the coordinates of the airport on one of the general run cards.

Either cards or tapes can be used as the deployment input medium. The coordinate system for the static deployment can be either in latitude and longitude or a nautical mile grid system as used by NAFEC. Computer runs using the airport option must have the transmitter deployment expressed in latitude and longitude and the receiver deployment in the NAFEC nautical mile grid system. In all cases, the aircraft altitude is in feet.

Further deployment description is included on the first three cards of the data card deck. (Format of cards is displayed in Figure C-1.) General run card number 1 contains two fields for deployment name and type, fields for transmitter and receiver percentages, and a field for an edit flag. This last field applies only to the static deployment, and, along with coordinates on an edit card, gives the user the option to analyze the interference in a small area within the overall deployment. The second general run card contains the airport latitude and longitude for the airport deployment input. The third type of card is used only when the edit option is desired. Two latitudes and two longitudes are entered on this card, and the resulting rectangular area is used to sort the input deployment. Only those aircraft within the rectangle are used for the interference analysis. Deployment editing can be used for air terminal or other critical air space analyses.

EQUIPMENT CHARACTERISTICS

Receiver characteristics are contained on one card and consist of name, noise level, antenna gains, and frequency. Gain values can be specified for three regions around an aircraft. These regions are:

(GENERAL RUN CARD NO. 1)

Item	Entry	Format	Columns
–	Deployment Characteristics	–	–
1.	deployment name	A6	1-6
2.	deployment type	A6	9-14
3.	number of deployment aircraft of (number of transmitter candidates)	I4	17-20
4.	number of altimeter entries	I2	23-24
5.	percentage of deployment with transmitters	I3	27-29
6.	percentage of deployment with receivers	I3	32-34
–	Deployment Data	–	–
7.	input source ("C" for cards, "T" for tape, "D" for dynamic)	A1	40
8.	coordinate system ("L" for lat/long, "G" for nautical mile grid)	A1	43
9.	edit deployment ("A" for all deployment, "E" for edit)	A1	46
–	Output Form	–	–
10.	lowest pulse count	I6	53-58
11.	pulse count bin size	I6	61-66
12.	lowest INR level	I4	69-72
13.	INR bin size	I2	75-76

Figure C-1. SEM Data Format
(Sheet 1 of 6)

(GENERAL RUN CARD NO. 2)

Item	Entry	Format	Columns
–	Miscellaneous	–	–
1.	fade probability (percent)	I3	1-3
2.	dedupe option ("N" for no, "D" for dedupe)	I1	6
3.	computer run time (in minutes)	I2	9-10
4.	random number seed	I11	13-23
5.	airpo[illegible] (deg)	F2.0	26-27
	(min)	F2.0	30-31
	(sec)	F2.0	34-35
6.	airport longitude (deg)	F3.0	38-40
	(min)	F2.0	43-44
	(sec)	F2.0	47-48

Figure C-1. SEM Data Format
(Sheet 2 of 6)

(LAT/LONG EDIT CARD)

(CARD No. 1, ITEMS 8 = L, 9 = E)

Item	Entry		Format	Columns
1.	northmost latitude	Deg	I2	1-2
		Min	I2	5-6
		Sec	I2	9-10
		Direction	I1	13
2.	southmost latitude	Deg	I2	16-17
		Min	I2	20-21
		Sec	I2	24-25
		Direction	I1	28
3.	eastmost longitude	Deg	I3	31-33
		Min	I2	36-37
		Sec	I2	40-41
		Direction	I1	44-45
4.	westmost longitude	Deg	I3	48-50
		Min	I2	53-54
		Sec	I2	57-58
		Direction	I1	61

Figure C-1. SEM Data Format
(Sheet 3 of 6)

(NAUTICAL MILE GRID EDIT CARD)

(CARD No. 1, ITEMS 8 = G, 9 = E)

Items	Entry	Format	Columns
1.	maximum X axis value	F6.2	1-6
2.	minimum X axis value	F6.2	9-14
3.	maximum Y axis value	F6.2	17-22
4.	minimum Y axis value	F6.2	25-30

Figure C-1. SEM Data Format
(Sheet 4 of 6)

(RECEIVER DESCRIPTION CARD)

Item	Entry	Format	Columns
1.	receiver name	A6	1-6
2.	receiver noise level (dBm)	F6.1	9-14
3.	antenna gain above aircraft (dBi)	F4.0	17-20
4.	antenna gain below aircraft and outside mainbeam (dBi)	F4.0	23-26
5.	antenna gain in mainbeam (dBi)	F4.0	29-32
6.	diameter of circular mainbeam (deg)	F3.0	35-37
7.	tuning range, minimum frequency (MHz)	F7.1	40-46
8.	tuning range, maximum frequency (MHz)	F7.1	49-55

Figure C-1. SEM Data Format
(Sheet 5 of 6)

(TRANSMITTER DESCRIPTION CARD)

(MAXIMUM OF 20 CARDSO

Items	Entry	Format	Columns
1.	transmitter name	A6	1-6
2.	transmitter power range, minimum (dBm)	F6.1	8-13
3.	transmitter power range, maximum (dBm)	F6.1	15-20
4.	antenna gain above aircraft (dBi)	F4.0	22-25
5.	antenna gain below aircraft and outside mainbeam (dBi)	F4.0	27-30
6.	antenna gain in mainbeam (dBi)	F4.0	32-35
7.	diameter of circular mainbeam (deg)	F3.0	37-39
8.	high altitude PRF	F5.0	41-45
9.	low altitude PRF	F5.0	47-51
10.	PRF change over altitude (feet)	F5.0	53-57
11.	tuning range, minimum frequency (MHz)	F7.1	59-65
12.	tuning range, maximum frequency (MHz)	F7.1	67-73
13.	proportion of transmitter environment	F3.3	75-77

Figure C-1. SEM Data Format
(Sheet 6 of 6)

1. Above the aircraft wing plane;
2. Below the wing plane but outside a conical region directly below the aircraft;
3. The gain of the conical region.

This conical region corresponds to the antenna mainbeam for radar altimeters or other antennas mounted beneath the aircraft. Mainbeam diameter can also be specified.

Characteristics for up to 20 transmitters can be accommodated and are the last cards in the data card deck. Transmitter name, gain regions, and frequency are similar to the receiver entries. Additional data on power, PRF, and proportion of transmitter environment are also needed for each transmitter to be considered. Transmitter power is entered as a range in order to simulate expected equipment tolerances. Power amplifier stability, cable loss tolerances, and antenna gain variations can be reflected in the power range fields. Two PRFs can be entered for radar altimeters. Since the PRF of some of these transmitters varies with altitude, PRF changeover altitude is also entered. If more than one transmitter type is to be considered in the transmitter environment, each card must contain a value for the proportion of the transmitter environment other than 1.0. In this manner, the various transmitter types can be divided in any proportion among the total transmitter population.

APPENDIX D

UHF TV STATIONS SUB-HARMONICALLY RELATED TO CAS

TABLE D-1

DOMESTIC UHF TV STATIONS (Sheet 1 of 2)

Chan.	Frequency (MHz) Aural	Video	Mainlobe ERP (dBm) Aural	Video	Call Sign	Latitude Longitude	City State
24	535.75	531.25	82.7	90.2	KAON-TV	35 28 04 N 94 26 15 W	Fort Smith, Ark.
↓	↓	↓	85.0	92.0	KMJ-TV	36 44 45 N 119 16 53 W	Fresno, Calif.
			60.5	67.5	KVCR-TV	34 05 20 N 117 18 44 W	San Bernardino, Calif.
			74.9	82.1	WEDH-TV	41 46 27 N 72 48 20 W	Hartford, Conn.
			77.0	84.1	WMFE-TV	28 33 31 N 81 35 38 W	Orlando, Fla.
			66.1	73.1	WMET-TV	39 20 20 N 76 40 02 W	Baltimore Md.
			74.5	83.9	WHTV-TV	32 19 40 N 88 41 28 W	Meridian, Miss.
			80.8	87.8	WCNY-TV	42 56 42 N 76 01 28 W	Syracuse, NY
			87.3	94.3	WDHO-TV	41 40 03 N 83 21 22 W	Toledo, Ohio
			77.2	87.0	WJET-TV	42 02 24 N 80 04 08 W	Erie, Pa.
			86.7	93.7	WWVU-TV	39 41 45 N 79 45 45 W	Morgantown W. Va.
25	541.75	537.25	81.0	88.0	WHIQ-TV	34 44 16 N 86 32 02 W	Huntsville, Ala.
↓	↓	↓	77.0	87.0	WACS-TV	31 56 15 N 84 33 15 W	Dawson, Ga.
			83.0	90.0	WEEK-TV	40 37 48 N 89 32 51 W	Peoria, Ill.
			77.0	84.0	WEHT-TV	37 51 56 N 87 34 04 W	Evansville, Ind.
			62.8	69.8	WKAS-TV	38 27 45 N 82 37 13 W	Ashland, Ky.
			80.9	88.6	WHAG-TV	39 39 35 N 77 57 57 W	Hagerstown, Md.
			74.8	84.8	WKNX-TV	43 23 32 N 83 55 32 W	Saginaw, Mich.

TABLE D-1. (Sheet 2 of 2)

Chan.	Frequency (MHz) Aural	Frequency (MHz) Video	Mainlobe ERP (dBm) Aural	Mainlobe ERP (dBm) Video	Call Sign	Latitude Longitude	City State
25	541.75	537.25	81.1	88.1	WNYE-TV	40 41 21 N 73 58 37 W	New York, N.Y.
			81.0	88.0	WUNK-TV	35 33 01 N 77 36 02 W	Greenville, N.C.
			80.0	87.0	WVIZ-TV	41 20 32 N 81 44 22 W	Cleveland, Ohio
			77.4	84.4	KOKH-TV	35 28 08 N 97 30 58 W	Oklahoma City, Okla.
			81.7	90.8	WOLO-TV	34 03 22 N 80 58 52 W	Columbia, S.C.
			82.2	72.2	KNDU-TV	46 06 11 N 119 07 47 W	Richland, Wash.
68	799.75	795.25	83.7	90.7	WKMJ-TV	38 22 02 N 85 49 53 W	Louisville, Ky.
			79.5	89.5	WQTV-TV	42 19 21 N 71 07 00 W	Boston, Mass.
			80.0	90.0	WWRO-TV	40 47 15 N 74 15 18 W	Newark-Asbury Pk., N.J.
69	805.75	801.25		-	-	-	-
70	811.75	807.25	61.1	70.2	WBGU-TV	41 22 33 N 83 38 34 W	Bowling Green, Ohio

TABLE D-2

FOREIGN UHF TV STATIONS (Sheet 1 of 6)

Channel	Frequency (MHz) Aural	Video	City Country	Latitude Longitude
28	532.75	527.25	Mt. Scuro, Italy	39 20 00 N 016 24 00 E
			Trieste, Muggia, Italy	45 36 00 N 013 44 00 E
			Terracina, Italy	41 19 00 N 013 13 00 E
			Spoleto, Italy	42 44 00 N 012 45 00 E
			Sellia, Italy	38 59 00 N 016 38 00 E
			Savona, Italy	44 19 00 N 008 29 00 E
			Sarentino, Italy	46 39 00 N 011 21 00 E
			S Giuliana, Italy	45 59 00 N 011 19 00 E
			Roma, Italy	41 55 00 N 012 27 00 E
			Postiglione, Italy	40 34 00 N 015 14 00 E
			Pescopagano, Italy	40 50 00 N 015 24 00 E
			Ozieri, Italy	40 35 00 N 009 00 00 E
			Langenburg, Germany	49 16 00 N 009 52 00 E
			Loerrach, Germany	47 36 00 N 007 39 00 E
			Hoher Bogen, Germany	49 15 00 N 012 54 00 E
			Kronach, Germany	50 13 00 N 011 20 00 E
			Huettental, Germany	50 54 00 N 008 01 00 E
			Hemer, Germany	51 24 00 N 007 45 00 E
			Hasperbach, Germany	51 20 00 N 007 26 00 E
			Gruenten, Germany	47 33 00 N 010 19 00 E

TABLE D-2. (Sheet 2 of 6)

Channel	Frequency (MHz) Aural	Frequency (MHz) Video	City Country	Latitude Longitude
28	532.75	527.25	Fahrnau, Germany	47 41 00 N 007 50 00 E
			Golbach, Germany	50 32 00 N 006 31 00 E
			Essen Werden, Germany	51 24 00 N 006 59 00 E
			Brandenkopf, Germany	48 20 00 N 008 09 00 E
			Boppard, Germany	50 11 00 N 007 36 00 E
			Bad Nauheim, Germany	50 21 00 N 008 46 00 E
			Altenglan, Germany	49 31 00 N 007 29 00 E
			Alfeld, Germany	51 58 00 N 009 47 00 E
			Wolfsberg, Austria	46 47 00 N 014 58 00 E
			EBBS Buchberg, Austria	47 38 00 N 012 15 00 E
			Schesslitz, Germany	49 57 00 N 011 03 00 E
			Schalksmuehlen, Germany	51 14 00 N 007 31 00 E
			Ludwigstadt, Germany	50 29 00 N 011 22 00 E
			Ruhpolding, Germany	47 44 00 N 012 41 00 E
			Wolfshagen, Germany	51 55 00 N 010 19 00 E
			Stuttgart Mitt, Germany	48 46 00 N 009 09 00 E
			Bologna, Italy	44 28 00 N 011 21 00 E
			Cagliari Capot, Italy	39 10 00 N 008 58 00 E
			Campo Dei Fior, Italy	45 52 00 N 008 46 00 E
			Isernia, Italy	41 37 00 N 014 17 00 E

TABLE D-2. (Sheet 3 of 6)

Channel	Frequency (MHz) Aural	Video	City Country	Latitude Longitude
28	532.75	527.25	Catania, Italy	37 34 00 N 015 06 00 E
			Ispicia, Italy	36 47 00 N 014 54 00 E
			Mione, Italy	46 26 00 N 011 02 00 E
			Malles Venosta, Italy	46 41 00 N 010 33 00 E
			Mondovi, Italy	44 20 00 N 007 45 00 E
			Mt. Raga, Italy	45 42 00 N 011 20 00 E
			Mt. Di Chiunzi, Italy	40 43 00 N 014 38 00 E
	533.25		Pontypridd, Great Brtn.	51 36 00 N 003 19 00 W
			Nelson Colne, Great Brtn.	53 51 00 N 002 16 00 W
			Kincardine, Great Brtn.	57 00 00 N 002 23 00 W
			E. Cornwall, Great Brtn.	50 31 00 N 004 26 00 W
			East Lincs, Great Brtn.	53 20 00 N 000 10 00 W
			Merthyr Tydfil, Grt. Brtn.	51 45 00 N 003 22 00 W
	533.75		Boisse Penchot, France	44 35 00 N 002 12 00 E
			Cannes Picours, France	43 29 00 N 006 54 00 E
			Chamonix, France	45 53 00 N 006 53 00 E
			Clermont Puydo, France	45 47 00 N 002 58 00 E
			Fecamp, France	49 46 00 N 000 23 00 E
			Forbach, France	49 11 00 N 006 56 00 E
			Grenoble, France	45 10 00 N 005 40 00 E

TABLE D-2. (Sheet 4 of 6)

Channel	Frequency (MHz) Aural	Video	City Country	Latitude Longitude
29	540.75	535.25	S Marco Lamis, Italy	41 42 00 N 015 40 00 E
			Rovereto, Italy	45 54 00 N 011 07 00 E
			Mt. Favone, Italy	41 36 00 N 013 38 00 E
			Mt. Arnato, Italy	43 27 00 N 012 12 00 E
			Macerata, Italy	43 18 00 N 013 27 00 E
			Guadamello, Italy	42 27 00 N 012 26 00 E
			Gutenstein, Austria	47 53 00 N 015 53 00 E
			MTE Castello, Italy	44 34 00 N 010 23 00 E
			Rhoen, Germany	50 28 00 N 010 00 00 E
			Untermuenstert, Germany	47 51 00 N 007 47 00 E
			Ueberlingen, Germany	47 45 00 N 009 08 00 E
			Neustadt Schww, Germany	47 56 00 N 008 13 00 E
			Neunkirchen Sr, Germany	49 22 00 N 007 12 00 E
			Neckargerach, Germany	49 24 00 N 009 03 00 E
			Bad Harzburg, Germany	51 53 00 N 010 34 00 E
			Duesseldorf, Germany	51 07 00 N 007 06 00 E
			Pescorocchiano, Italy	42 12 00 N 013 08 00 E
			Buehlertal Bad, Germany	48 41 00 N 008 11 00 E
			Bad Schwalbach, Germany	50 09 00 N 008 04 00 E
			Ellenz Mosel, Germany	50 07 00 N 007 13 00 E
			Fichtelberg, Germany	49 58 00 N 011 50 00 E

TABLE D-2. (Sheet 5 of 6)

Channel	Frequency (MHz) Aural	Video	City Country	Latitude Longitude
29	540.75	535.25	Heubach, Germany	48 47 00 N 009 57 00 E
			Gross Steinum, Germany	52 17 00 N 010 53 00 E
			Heidelberg, Germany	49 26 00 N 008 45 00 E
			Muehlheim, Germany	48 02 00 N 008 54 00 E
			Portofino, Italy	44 20 00 N 009 10 00 E
			Idaroberst 3, Germany	49 27 00 N 007 15 00 E
			Kusel, Germany	49 32 00 N 007 25 00 E
			Meschede 1, Germany	51 23 00 N 008 17 00 E
			Reggio Calabr, Italy	39 09 00 N 015 28 00 E
			Seesen, Germany	51 54 00 N 010 10 00 E
			Trabentrarbach, Germany	49 58 00 N 007 07 00 E
			Firenze, Italy	43 50 00 N 011 14 00 E
			Acri, Italy	39 29 00 N 016 23 00 E
			Goes, Netherlands	51 31 00 N 003 53 00 E
			Foligno, Italy	42 59 00 N 012 47 00 E
			Arzana, Italy	39 56 00 N 009 32 00 E
			Carini, Italy	38 08 00 N 013 15 00 E
			Obernburg, Germany	49 49 00 N 009 07 00 E
			Pforzheim, Germany	48 52 00 N 008 41 00 E
▼	▼	▼	Cortin Ampezzo, Italy	46 32 00 N 012 10 00 E

TABLE D-2. (Sheet 6 of 6)

Channel	Frequency (MHz) Aural	Video	City Country	Latitude Longitude
29	540.75	535.25	Chiaromonte, Italy	40 07 00 N 016 13 00 E
			Oberfell, Germany	50 15 00 N 007 26 00 E
	541.75		Nancy Malzevil, France	48 43 00 N 006 12 00 E
			Beaufort Gerva, France	44 41 00 N 005 05 00 E
			Nantes Htegoul, France	47 11 00 N 001 26 00 W
			Arrens, France	42 59 00 N 000 11 00 W
			S Claude 1, France	46 26 00 N 005 52 00 E
			Sarrancolin, France	42 58 00 N 000 24 00 E
62	804.75	799.25	Innsbruck, Austria	47 13 00 N 011 28 00 E
	805.25		High Wycombe, Great Brtn.	51 38 00 N 000 46 00 W
			So Lancs, Great Britain	53 38 00 N 002 31 00 W
	805.75		Dijohn S. Georges, France	47 08 00 N 004 56 00 E
63	813.75	807.25	Sens, France	48 18 00 N 003 17 00 E
	813.25		Salisbury, Great Britain	51 03 00 N 001 48 00 W
			Reigate, Great Britain	51 15 00 N 000 12 00 W
			Oxfordshire, Great Brtn.	51 47 00 N 001 11 00 W
			Anglesey, Great Birtain	53 18 00 N 004 08 00 W
			Brierly Hill, Great Brtn.	52 28 00 N 002 07 00 W
			Perthshire, Great Brtn.	56 33 00 N 002 59 00 W

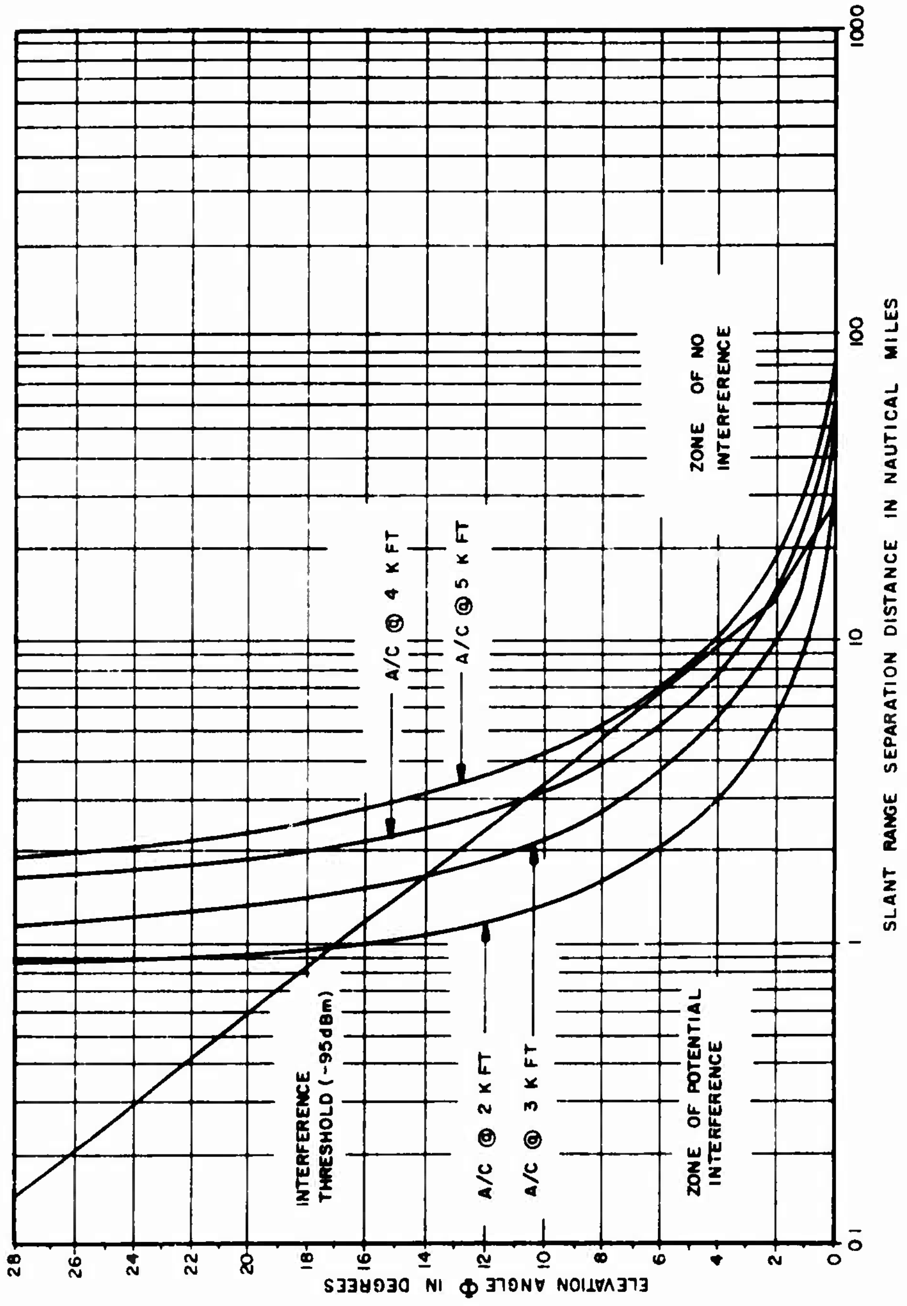

Figure D-1. Required Separation Distance Between CAS Equipped Aircraft and TV Emitters for Varying Altitudes

APPENDIX E

TROPOSPHERIC SCATTER TERMINALS SUB-HARMONICALLY RELATED TO CAS

TABLE E-1

SUB-HARMONIC TROPOSPHERIC SCATTER TERMINALS
(Sheet 1 of 3)

FREQUENCY (MHz)	LATITUDE	LONGITUDE	LOCATION	
796.45	69 55 33 N	128 58 16 W	Nickolson Peninsula	Canada
"	69 44 10 N	163 01 16 W	Point Lay	Alaska
796.56	65 00 00 N	012 00 00 E	Country Wide	Norway
"	39 25 00 N	029 51 00 E	Kutahya Dagi	Turkey
798.00	65 31 32 N	037 10 31 W	East Coast	Greenland
"	66 29 01 N	046 17 22 W	Westerly Ice Cap	Greenland
"	66 39 51 N	061 21 43 W	Cape Dyer	Canada
"	58 42 18 N	156 39 54 W	King Salmon	Alaska
"	66 04 07 N	153 40 45 W	Indian Mtn.	Alaska
"	66 04 07 W	153 40 45 W	Indian Mtn.	Alaska
"	58 42 18 N	156 39 54 W	King Salmon	Alaska
"	58 07 40 N	135 25 49 W	Hoonah	Alaska
"	61 37 15 N	149 15 12 W	Neklasson Lake	Alaska
"	55 05 09 N	131 35 18 W	Smugglers Cove	Alaska
"	60 04 01 N	142 25 01 W	Yakataga	Alaska
799.71	68 28 33 N	113 13 11 W	Lady Franklin Pt.	Canada
800.00	43 09 07 N	075 37 03 W	Verona	New York
"	43 13 32 N	078 57 38 W	Youngstown	New York
"	43 13 30 N	077 18 15 W	Ontario Cntr.	New York
"	15 10 48 N	145 46 49 E	Saipan	Marianas
800.88	40 54 00 N	035 24 00 E	Koca Yunusbasi	Turkey
802.96999	68 26 15 N	089 43 06 W	Pelly Bay	Canada

TABLE E-1. (Sheet 2 of 3)

FREQUENCY (MHz)	LATITUDE	LONGITUDE	LOCATION	
804.00	64 15 00 N	015 21 00 W	Hoefn	Iceland
"	65 02 03 N	147 29 59 W	Pedro Dome	Alaska
"	52 58 25 N	168 51 12 W	Nikolski	Alaska
"	52 58 25 N	168 51 12 W	Nikolski	Alaska
"	61 46 53 N	165 57 05 W	Cape Romanzof	Alaska
"	65 02 03 N	147 29 59 W	Pedro Dome	Alaska
"	61 46 53 N	165 57 05 W	Cape Romanzof	Alaska
806.22	71 19 27 N	156 38 29 W	Pt. Barrow	Alaska
809.48	66 39 51 N	061 21 43 W	Cape Dyer	Canada
"	69 35 02 N	120 47 16 W	Clinton Pt.	Canada
809.6	32 24 00 N	015 04 00 E	Misurata	Libyan Arab Republic
810.00	64 15 00 N	015 21 00 W	Hoefn	Iceland
"	52 58 25 N	168 51 12 W	Nikolski	Alaska
"	64 25 40 N	156 49 59 W	Kalakaket Creek	Alaska
"	66 29 01 N	046 17 22 W	Westerly Ice Cap	Greenland
"	59 40 52 N	151 37 23 W	Diamond Ridge	Alaska
"	59 40 52 N	151 37 23 W	Diamond Ridge	Alaska
"	58 39 04 N	162 01 56 W	Cape Newenham	Alaska
"	58 39 04 N	162 01 56 W	Cape Newenham	Alaska
"	64 25 40 N	156 49 59 W	Kalakaket Creek	Alaska

TABLE E-1. (Sheet 3 of 3)

FREQUENCY (MHz)	LATITUDE	LONGITUDE	LOCATION	
810.00	61 37 15 N	149 15 12 W	Neklasson Lake	Alaska
810.1	25 25 10 N	081 50 10 E	Allahabad	India
"	18 55 00 N	073 00 00 E	Bombay	India
"	22 28 00 N	088 50 00 E	Calcutta	India
"	28 42 00 N	077 20 00 E	Delhi	India
"	13 02 00 N	080 22 00 E	Madras	India

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